FEB 4 1983

830-A-10

NAS 1.55:2246

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NASA Conference Publication 2246

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Human Factors Considerations in System Design

Proceedings of a NASA symposium held at
Goddard Space Flight Center
Greenbelt, Maryland
and
University of Maryland
College Park, Maryland
May 25-26, 1982

NASA

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NASA Conference Publication 2246

Human Factors Considerations in System Design

Edited by
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NASA
National Aeronautics
and Space Administration

Scientific and Technical
Information Branch

1983

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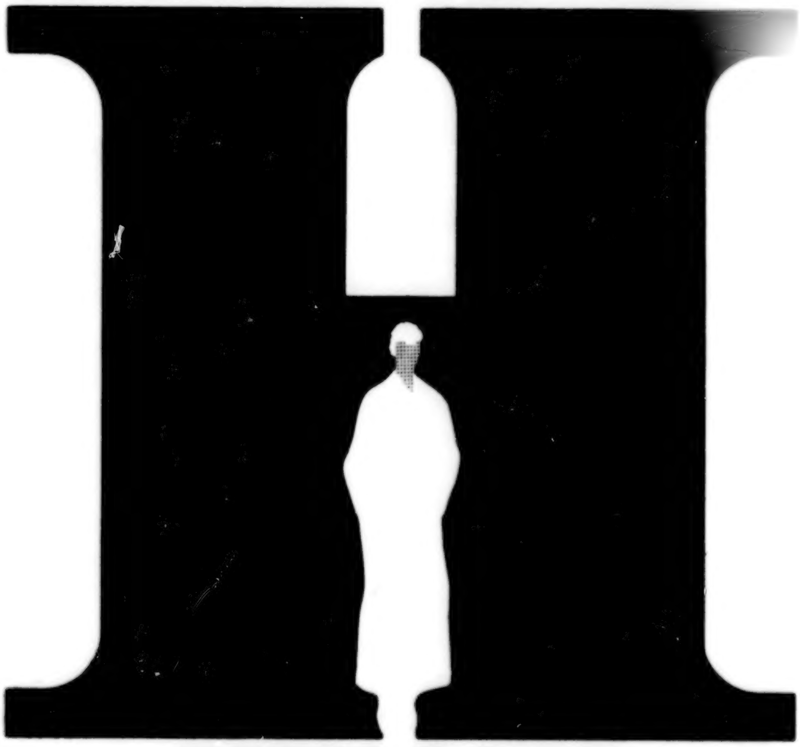

HUMAN FACTORS

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INTRODUCTION

The NASA-Goddard symposium on Human Factors Considerations in System Design was a very successful introduction to human factors for engineers, analysts, and operations personnel at Goddard. The symposium helped to establish human factors as a legitimate and significant component in the design process. Human factors aspects, particularly in increasingly automated command and control, as well as office environments, are becoming an important determinant of the efficiency of the human-computer interface, and as a result, an important determinant of overall system effectiveness.

We were priviledged, on the first day of the symposium, to have a very distinguished set of human factors specialists who presented a multi-faceted perspective on human factors in system design. Dr. Alphonse Chapanis, an internationally respected human factors specialist, gave the keynote address which provided historical perspective on the need and evolution of human factors as a discipline. Mr. James Jenkins, human factors specialist from the U.S. Nuclear Regulatory Commission, followed this up by sharing some of the human factors problems and human factors research being studied in the nuclear power plant industry. The afternoon of the first day was devoted exclusively to human factors issues of computers. Dr. Ben Shneiderman addressed some of the informational dimensions of software design and Dr. James Foley reviewed and critiqued a variety of interactive techniques and devices which enhance human-computer dialogue. This proceedings contains summaries or papers related to the talks of each of these speakers.

The second day of the symposium had a change of format. Rather than large plenary sessions, parallel workshops were held addressing topics, in both the applications and research domains, that were specifically tailored to Goddard systems. Workshops were generally small, encouraging audience interaction. The substance of each workshop has been documented in this proceedings. In addition, a summary of the comments from each workshop is included. Symposium participants completed an evaluation on both days; a synopsis of their responses is also included.

Finally, in an effort to make this proceedings a useful reference for system designers in addition to a documentation of the symposium itself, a bibliography of literature on human factors related to command and control issues has been included.

The symposium and the proceedings were the result of hard work by many people. I would especially like to thank Lisa Stewart for her efforts in planning and preparing the symposium facilities and program, and Paula Van Balen who has been primarily responsible for the often thankless task of compiling this proceedings.

Christine M. Mitchell
George Mason University

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WELCOMING REMARKS

MS. KAREN L. MOE
MR. JOHN J. QUANN

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WELCOMING REMARKS, MS. KAREN L. MOE

Good morning. The reactions that I am getting toward this symposium are indicative of something that is happening in the computer field today. As systems have become more sophisticated and complex, our view of computer systems has grown from electronic components to hardware and software engineering. It's about time that we expand that systems view to include the people who are running and using those systems. So the purpose of human factors, from our perspective, is to examine systems that include people, their capabilities and their limitations, so that we have a more complete systems analyses approach when developing our own systems. That is basically the motivation behind the development of this symposium.

This conference is being sponsored by the Human Factors Research Group (HFRG) which is composed of people from the Mission and Data Operations Directorate (Code 500) and various universities who are supporting research projects under the Office of Aeronautics and Space Technology (OAST), and the Office of Space Tracking and Data Systems (OSTDS) at NASA Headquarters. These two groups have been providing sponsorship for various research activities in the human to machine interface, and in the automation of command and control systems. From this initial effort we have organized the Human Factors Research Group. Later today Walt Truszkowski will be talking to you more specifically about the charter and the long-range plans of this group.

Also, I'd like to touch upon our objectives for the workshop. Basically, there are three. The first objective is that human factors is a new discipline in terms of its visibility; a lot more people are becoming involved in human factors and recognizing its importance. Therefore, the first step is an educational process so that we are all talking on the same basis. What is human factors? I think our program today will set the stage for the answer to that question. We have four excellent speakers who will be presenting their views from their continuing research in human factors issues.

The second objective is to give a progress report on our Human Factors Research Group and to determine in what direction we are headed. We have some workshop sessions scheduled tomorrow where HFRG members will be presenting various facets of what is being done here at Goddard in terms of human factors research.

The third objective is to get feedback from people at Goddard and those outside of Goddard who are participating in the conference. We would like feedback to the HFRG on whether the topics that we are addressing here today are indeed the right topics from your perspective. We eventually hope to implement our findings in the design of new systems at Goddard.

Now, I would like to start off our program by introducing John Quann to give our official welcome. He is the Director of the Mission and Data Operations Directorate. I am very pleased with the kind of support we have received for our Human Factors Research Group since the backing of management is a necessary step in being able to formulate an effective research program.

WELCOMING REMARKS, MR. JOHN QUANN

On behalf of the Mission and Data Operations Directorate and the Office of Space Tracking and Data Systems (OSTDS, NASA Headquarters) and also on behalf of Goddard management, I'd like to welcome you to the first conference on human factors.

Whenever I think of human factors, I think of avionics, particularly aircraft. For example, the Ames Research facility is conducting research on heads-up displays. The Wallops Island King Air aircraft (NASA) has a CRT display built into the control panel. As the pilot goes through his checklist, the automated display functions in a roll-up sequence. Also, a human synthesized voice is activated when critical procedures are necessary such as "Dive" or "Pull up." All of this is part of human factors research being conducted in industry.

This past April, 20/20 showed a sequence on U.S. tactical air power that included several impressive heads-up displays. The pilot never had to take his eyes off of what was immediately displayed in front of him to do all sorts of things from flight control to target tracking and destruction.

For STS flight 5, the Johnson Space Center has planned a heads-up display that will be projected on the cockpit of the Shuttle to be used during several maneuvers including the landing.

Recently I received a conference brochure on the International Conference on Computer Communications being held in London, England. In their program they don't have one session on human factors, they have three: Human Factors—Man/Machine Interface, Human Factors—The Friendly System, and Human Factors In Office Systems. So, all of a sudden, human factors is taking on a scope and significance that I hadn't really considered before.

Yesterday at Management Council, I decided I'd try my hand at a definition of what I thought human factors meant. My definition included man and his interaction with his work environment and that includes computers. It is this interaction with the environment that would make him either more productive, more effective, or more efficient in the performance of his job.

Karen's definition concentrated on man/machine communication, man/machine interface, the division of effort between the two, what the limitations and the capabilities of each were. The research now in progress concerns both an evaluation of those things the human is better capable of doing and those the machine is better capable of doing and how both man and machine interact.

Here at Goddard, human factors is playing a significant role in the ERBE Control Center design, and it will certainly play a part in the Space Telescope Control Center design. Space Telescope is going to be in orbit for aproximately 15 years and will be operated through a generation or perhaps two of controllers. If human factors is not a consideration at the very beginning of that project, it is in for trouble. The system life cycle is going to be significantly more expensive over that time frame than it would be if human factors was a consideration.

Human factors in the operation of control centers are critical in the way that information is formulated, and the way it is organized and displayed, so that a person operating the spacecraft can better receive and perceive information and make better and faster decisions.

A Space Station is possible for a new NASA initiative someplace in the 1985, 1986 time frame. Several working groups have already been organized but human factors is being considered separately. I don't consider human factors as separate to anything; it's a related discipline. Why human factors should be a separate working group I hadn't considered. It will have to communicate with several other working groups such as Data Management which I chair. Certainly we are very aware and concerned about the human factors element in the Data Management Working Group.

To get back to a definition again, I would suspect that human factors is not a discipline unto itself, but some combination of psychology, some combination of engineering; it touches on how people and machines interact; it touches on how people actually make decisions, and what they need to make decisions. It's imbedded within the other disciplines.

The National Academy of Sciences has come out within the last week with a document called "Data Management and Computation." In terms of human factors, an issue that is highlighted concerns the little thought given, in the 20 some odd years since spacecraft have been flying, to man/machine interaction. The report takes us to task on that count. It goes on with the recommendation that specific emphasis must be given to the user interface and to the way man interfaces with machines.

On that note, I think the symposium today is a step to rectify that situation. I want to wish all of you a very successful symposium and make good use of the two days. I hope you enjoy the learning experience.

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INTRODUCTION TO HUMAN FACTORS CONSIDERATIONS IN SYSTEM DESIGN

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INTRODUCTION TO HUMAN FACTORS CONSIDERATIONS IN SYSTEM DESIGN[1]

- A two-engine aircraft with forty people aboard roars down the runway for take off. Just as it lifts off, the right engine quits. Pilot and copilot reach down to feather the right engine and in so doing hit the switch for the left engine. The aircraft, now without any power, plows into the field at the end of the runway.
- A young factory worker unintentionally had four fingers of her left hand cut off when her right hand inadvertently activated the ON button while she was cleaning debris from the jaws of a machine she had just turned off.
- A farmer's wife helplessly watched her husband drawn into the claws of farm machinery while she frantically and unsuccessfully searched for the control to stop the machine.

What is the common tie among these incidents? It is the conflict between man and the machines that he is required to operate in his daily life. There have always been accidents, but for our forefathers accidents were relatively simple affairs being mostly falls, natural calamities, or encounters with wild or unruly beasts. To these, modern man has added devices of his own creation–tools, machines, jobs, and environments with enormous potential for destruction. Moreover, the hazards involved are often hidden. Worse still, "human factors" has shown that many of the hazards associated with modern devices are traps that often lead one into committing errors and having accidents because of the way they are designed.

Of course, not all stories about man/machine conflicts result in disaster. Many, such as trying to find the control for the heater in a rented car or the right switch to turn on under a coffee pot, are merely instances of the irritations and frustrations that plague us. All of us, at one time or another, have exclaimed, "What a stupid way to build this thing. If only they'd put this over there instead of here!" And it might have been anything, your stove, bathroom, or automobile. If you have engaged in such an outburst you have already introduced yourself to the field of human factors.

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[1] This condensed version of Professor Chapanis' talk was prepared by Paula Van Balen from a tape recording made at the conference.

What is human factors? A brief definition is that it is designing for human use, or humanizing technology. A more academic definition is that human factors discovers and applies information about human abilities, limitations, and other characteristics to the design of tools, machines, systems, tasks, jobs, and environments for safe, comfortable, and effective human use. The term "human factors" is used almost exclusively on the North American continent; almost everywhere else people use the term "ergonomics". Ergonomics comes from two Greek words, "ergon" meaning work, and "nomos" meaning laws of. Human factors and ergonomics are multidisciplinary fields drawing from anthropology, engineering, psychology, computer science, and physiology, to name a few. Although human factors and ergonomics are roughly equivalent, they do have some different emphases as will be described later.

There is nothing earth shaking about the idea of designing for man's use or needs. Ever since man started fashioning tools and implements, they were designed and built to suit his physique and his natural movements. If we look around us, we find lots of things that work well even though they haven't had the benefits of systematic human factors work. Why then have a special field called human factors and what can it do that is so special?

To answer this question consider the history of technology. Technology has advanced more in the last hundred years than in all of man's history up to that time. In the last hundred years not only has society become more mechanized, but our machines have become larger, more dangerous, and more complex. There have been enormous increases in the amount of machine horsepower and in the speed of transportation. These slides depict the total machine horsepower available in the United States today. If we convert it to human power, each person in the United States has the equivalent of a thousand human slaves.

Machines these days have also begun to exceed man's biological capacity to respond. A dramatic example is the speed attained by modern spacecraft. The escape velocity of a space capsule is about 27,000 mph or 7 miles per second. A simple comparison of this speed against the speed with which the human eye converts electromagetic energy to sight (5/100 of a second),shows that what you see now outside a space capsule, actually happened about a third of a mile ago!

These changes have created new demands from society. People are demanding that the products, systems, and machines they deal with must be safe, reliable, convenient, and easy to use. This is the reality that confronts designers, engineers, and manufacturers.

Origins of Human Factors and Ergonomics

Human Factors originated largely during WWII. It was the effort of biological, psychological, and medical scientists to solve the man/machine problems that had been created by the instruments of war new at that time: radar, sonar, and high-flying aircraft. The problems raised by these machines involved questionss of psychomotor skill, perception, and mental capacities, like: How much optical distortion can a pilot tolerate in a wind screen? and, How much information can a man take in from a radar screen? These were psychological and complicated questions, questions that could no longer be answered by common sense or intuition. Experimental psychologists who studied human performance were equipped to tackle these questions because they had developed methods for analyzing, studying, and providing reliable data to solve these human problems. Because of this know-how, American psychologists of that type were often asked to become members of study and design teams in America. In Europe, however, the main man/machine problems arose from heavy work in industry, in mining, in forestry, and in agriculture. These problems were largely concerned with physical stress. Because of these origins, ergonomists in Europe are more likely to be work physiologists.

Philosophy of Human Factors

The people in the human factors profession share a common kind of philosophy. Foremost is our insistence that machines exist only for one purpose, and that purpose is to serve people. Our main concerns are inputs to, and outputs from, the human. The output from a computer is a human input; the input to a computer is a human output. Our point of view is the reverse of the typical engineering point of view.

A second point is that we are empirical. We prefer to base our design recommendations not on opinions, but on data collected from task analyses, surveys, field evaluations, and experiments.

Third, we are uniformly concerned about individual differences. Consider that half the people are below average in intelligence, that the majority of them speak a language other than the five official languages of the United Nations, and that physical characteristics such as height vary greatly around the world. To cope with these individual differences, human factors specialists generally design for the middle 90 percent, from the 5th to the 95th percentiles of a population, whether it be for anthropometric dimensions, mental capacities, or skills. The measures we use to quantify these individual differences are means, standard deviations, percentiles, correlation coefficients, probabilities, and confidence limits. Given enough time and resources, the human factors specialist can give you information with any degree of precision you want. It's not easy, and it takes time, but it can be done.

Another important point of our philosophy is that design has to start with the user, with what is referred to as user characterization. Once you know for whom you are designing, you can design specific components to suit the intended user.

Finally, we believe that to be effective, human factors considerations must be introduced at the start of system design. Once a design is frozen, only cosmetic changes can be made. These never solve basic design faults.

Goals and Objectives

The best way to show where human factors has been and where it is going is to trace the evolution of its objectives. In the beginning, human factors was mainly concerned with reducing errors and increasing safety in handling military machines. We soon found that good human factors could also increase the reliability of man/machine systems, reduce training, and improve maintenance. Other benefits surfaced as human factors was applied in industry: increased efficiency, increased productivity, and improved work environments. To this list, European ergonomists added reduction of fatigue and physical stress, increase in human comfort, and reduction of boredom and monotony.

In the 1960s, human factors began to be influential in the design of consumer products. The goals then expanded to include convenience of use, ease of use, and user acceptance. Most recently, again due to European ergonomists, the field of human factors is expanding to consider increased job satisfaction and improved quality of life. As a result of these gradual changes, it is difficult to define the boundaries of the field at the present time. There is some uncertainty whether human factors should be concerned with sociotechnical systems. Should it be concerned with the effects of our designs on such things as livability, crime, pollution, and recreation? The future will better define the boundaries of the field by the kind of work the professionals actually do.

Two things help us cope with these numerous goals and objectives. The first is that only subsets of them are generally relevant in specific areas of specialization . In the military services, for example, reducing errors, increasing safety, improving maintainability, increasing reliability, reducing training requirements, and reducing manpower requirements tend to be emphasized. On the other hand, if you work with consumer products, you are likely to find greater emphasis put on reduction of errors, increase in safety, increase in human comfort, increase in usability, and increase in user acceptance. In industry, more emphasis is generally put on increased efficiency, productivity, improvements in the working environment, reduction in fatigue and physical stress, and reduction in boredom and monotony.

The second thing that helps us deal with these multiple objectives is that they are usually correlated. Machines, systems, and jobs that are well human engineered are not only safer, but they are also generally easier to use, they are more efficient, and they result in greater productivity. If he reduces monotony and boredom, the human factors engineer usually finds he has also increased safety, reduced errors, and increased efficiency. If you increase maintainability, you usually find that you have also increased reliability, increased usability, and reduced training requirements. The fact that such correlations exist among these objectives means that the list is not quite as difficult to deal with as you might suppose when you first see it.

Not So Common Sense

One of the problems those of us in the field must deal with is the comment "Well after all, it is just common sense." Let me assure you it is more than common sense. Here are some examples that illustrate this point. Take this medicine bottle with a warning on the label. I defy you to read it. It's printed in brown on a tan background in a size of type that is much smaller than Elite typewriter type. Was it common sense that designed this label? Take this computer terminal. It offers several features that are handy for the user. One feature (a key) will make the unit inoperable to other persons. But where in the manual can you find how to operate this device? The index doesn't show it under "key", nor "lock". It's indexed under "security key lock." Is this a common sense designation? Also, a handy interactive device cannot be located in the index under "pointer," "pen", "light pen," or "stick." It's indexed under selector light pen. It's a common sense idea to have warning lights where you can see them. So, was it common sense that placed warning lights behind the operator of this vehicle, as this slide shows? In nuclear power plants you can find examples of mirror imaging, the configuration of controls and displays on a panel is just the reverse of the configuration on the panel next to it. Operators curse these because they never know where they are. Another long-time problem in human factors is the inadvertant activation of controls. In this picture you can see there is a control under the operator's toe which he could kick out of position as he walks by it. The point I want to make is well expressed in an editorial by the editor of Infosystems when he wrote "Common sense is not so common."

The best way to summarize what we know would be to browse through the table of contents of some large handbook. The bible of our profession is The Human Engineering Guide to Equipment Design (1972). It contains a chapter on system and human engineering analyses; man as a system component; and the visual presentation of information dials, gauges, lights, radar screens, and devices of that kind. Other chapters cover auditory forms of presentation, such as buzzers, gongs, diaphones, and other devices; speech communication; man/machine dynamics, dealing generally with the dynamics of closed loop tracking systems; data entry devices and procedures, dealing generally with typewriter and computer keyboards; the design of controls, levers, pedals, switches; the design of individual work places; the design of multiman/machine work areas; engineering anthropology, dealing with the sizes and shapes that people come in; designing for maintainability; training system design; training devices design; and human engineering tests and evaluations.

System Development and Design

Let us now turn to the system development process. It proceeds in different ways depending on where you are and the kind of system you are dealing with. However, there are general features that characterize most development activities.

Human factors can contribute to the development process in many ways. The first way, for many kinds of systems, is establishing user requirements. In the computer field, especially for computers that are designed for widespread and international use, this is a very critical part of the system development process. Some tremendous errors have been made in the development of systems because these requirements were not properly met. The requirements that we are concerned with here are, of course, anthropometric dimensions for the design of computer terminals and workspaces. You will find now in advertisements a lot of emphasis being placed on ergonomically-designed work stations and a lot of concern about the arrangement of the terminal keyboard. But there are other important requirements to consider, like mental requirements. Is your system going to be used by people in general, members of the population at large, or is it going to be used primarily by specialists? The way you design the system depends on the answer to that question. We have had some enormous failures because of inadequate attention to this question. For example, some American computerized checkout systems for grocery stores were never bought in Europe because the designer who designed them didn't know that throughout most of Europe the denominations of various bills come in different sizes. He had designed cash register terminals with compartments that were all of the same size. Such an obvious thing, and yet obviously it had not met the user requirements for that particular system. This whole businesss of user requirements is for many systems the most important part of the process.

The next phase is system design which very often involves many successive steps. It starts with drawings and proceeds, sometimes, through breadboard models and prototype development. In all of these phases, even the drawings, human factors specialists can use simulation techniques to try to find out whether or not there are going to be incompatibilities between the system, the inputs and the outputs, and the abilities of the users who will be interacting with the systems. As you get into the prototype systems, there may be more elaborate tests and evaluations.

Another area in which human factors contributes is documentation. Systems are of no use if users don't understand how to use the system. A great deal of the documentation, the manuals that go with machine systems, are inadequate for the intended users. Millions of dollars of equipment have been wasted because people didn't know how to operate the system that they were provided with. A good example is what I call the promise and the reality of using FORTRAN IV on the IBM/360 System. The manual promises that learning how to use a computer is as easy as driving a car. It goes on to say that many people who have no detailed knowledge of how an automobile runs have become excellent drivers. After looking through the FORTRAN IV manual, one realizes that this is not at all like trying to drive a car. The reality is bewildering complexity. It is examples like this that prompt many of the complaints found in articles and journals. This whole area of documentation and how you design it is an extremely important part of human factors.

Establishing personnel requirements is another human factors contribution to systems development, and by this I mean system staffing. For example, how many people will be required to operate the system, how will they be selected, what are the characteristics that you need to select them for? How will you train them, what kinds of training will be required in order that they can use the system?

Human factors also contributes to product testing. Having designed the system, having written the documentation, having trained the people, then you put the whole combination to test to find out if it does what it is supposed to do. Does it do what you think it is going to do; are you going to run into problems? These tests of operators and systems involve very complicated procedures because they are not as simple as engineering tests. You again have to deal with this very strange and difficult object called a person. To get reliable data from product tests is a complicated procedure.

Something that we often don't think about is the installation. When a product has been designed and you have it built and documented, established the personnel requirements, and you've tested it, it then has to be installed. There are many ways in which human factors specialists can contribute to the installation process, particularly of complicated systems, to make the process easier, more effective, to make it so that it can be consumer-installed rather than field engineer-installed.

There are also human factors problems involved in maintenance. These involve simple things, sometimes, like designing for maintenance. For example, at Lowry Air Force Base, I was astonished to discover that in the exercises that are conducted by maintenance people under simulated biological and chemical warfare, they have to wear large suits which protect them from the contaminants. But when they do, they can't maintain the aircraft because they can't get their gloved hands into the apertures that have been built into the aircraft. Maintenance may involve the design of special kinds of maintenance tools that may be required. And maintenance involves fault-finding procedures: What's the best way to diagnose a fault in a large system?

Once the system has been designed and put into use we have field evaluations. How is it going out there in the field? What problems are users encountering? This very often results in engineering changes which might go back to produce Models 2, 3, and 4 of the system.

These are some of the ways in which human factors contributes to the system design process. Although human factors has a large body of principles, data, and design recommendations, there are a lot of things we don't know. So one of the most important things we do is to design and conduct tests, evaluations, and experiments to get the answers that we need and don't have. One reason why we don't have all the data we need is that frankly we are outnumbered: there are only about 4 thousand human factors specialists and probably a million engineers in the United States. Engineers are producing new technology and new devices much faster than we can do the research to get the answers we need. Doing studies is something we spend a great deal of time at to get the kinds of data we need.

Employers of Human Factors Professionals

The largest single employer of human factors specialists is business and industry. The next largest employer is academia, and then we find human factors specialists in government, military organizations, consulting firms, utilities and as self-employed persons. As you might suppose, because of its small size, the profession is in a very healthy state at the present time. Universities cannot turn out graduates fast enough to keep up with the demand in the United States.

Human Factors Societies

Here are some of the societies that serve the profession world wide (figure 1). Human factors is pretty widespread throughout Europe, parts of Asia, and Australia. All of these are joined in an umbrella organization called the International Ergonomics Association (IEA). The IEA holds international Congresses every 3 years and many smaller conferences and symposia on selected ergonomic topics in-between various Congresses. The list presented here does not cover all of the ergonomists of the world. We know, for example, that there is a very substantial group of them in the USSR, but for political and other reasons the Soviets have never joined the IEA, although they do come to our meetings and other meetings that are sponsored by the western societies. It's hard to know how many human factors professionals there are worldwide; no one has ever tried to make the count.

The Human Factors Society has 9 technical interest groups; they are in aging, computer systems, consumer products, the educators professional group, environmental design, industrial ergonomics, safety, training, and visual performance. These smaller groups all publish newsletters containing information of special interest to their members. A number of these technical interest groups also schedule workshops and conferences separate from the parent organization—they have special sessions at the annual meeting.

You don't become a human factors professional just by calling yourself one. It isn't something that you can learn in 1 or 2 weeks. Being human isn't enough qualify as a human factors engineer. Training in human factors or ergonomics is carried out in a number of educational institutions. The International Directory of Educational Programs

HUMAN FACTORS SOCIETIES

- ERGONOMICS SOCIETY (UNITED KINGDOM)
- ERGONOMICS SOCIETY OF AUSTRALIA AND NEW ZEALAND
- GESELLSCHAFT FÜR ARBEITSWISSENSCHAFT
- HUNGARIAN SOCIETY FOR ORGANIZATION AND MANAGEMENT SCIENCE

- HUMAN FACTORS ASSOCIATION OF CANADA
- HUMAN FACTORS SOCIETY (USA)
- JAPAN ERGONOMICS RESEARCH SOCIETY
- NEDERLANDSE VERENIGING VOOR ERGONOMIE
- NORDIC ERGONOMIC SOCIETY
- POLISH ERGONOMICS SOCIETY
- SOCIETA ITALIANA DI ERGONOMIA
- SOCIÉTÉ D'ERGONOMIE DE LANGUE FRANÇAISE
- YUGOSLAV ERGONOMICS SOCIETY

FIGURE 1

in Ergonomics and Human Factors, published by the International Ergonomics Association lists 156 educational programs in 28 different countries around the world. The United States has the largest number. There are some 66 colleges and universities in the United States with some program in this specialty.

A little over half of the programs in the United States are in some kind of engineering department; generally industrial engineering, system engineering, management engineering, or operations research. About 40 percent are in psychology departments and the rest are scattered in other departments.

Human factors professionals publish in a wide variety of scientific and professional journals. The following 5 are specifically dedicated to articles of this kind:

1. HUMAN FACTORS - published by the American Human Factors Society.
2. ERGONOMICS - published by the Ergonomics Society of Great Britain.
3. ZEITSCHRIFT FÜR ARBEITS WISSENSCHAFT - published by the German Gesellschaft Für Arbeitswissenschaft.
4. APPLIED ERGONOMICS - a commercial publication of Great Britain.
5. INTERNATIONAL JOURNAL OF MAN/MACHINE STUDIES - another British commercial publication

Let me wind up briefly with what I've tried to tell you in this lecture. I think we're entering into an era when product usability, ease of use, product acceptance, and human factors are becoming more and more important. These are hard things to measure, they are hard to specify, they are hard to qualify; however, that does not mean that you can ignore them. There is a profession that can help in the search for these illusive human goals. It's a profession that is well established but small. It's been around for a reasonably long time, and it's a profession that is in great demand from industry.

You don't become a human factors professional just by being human. Specialized training courses are taught in the subject matter in about 66 colleges and universities around the United States. Although the number of graduates in the profession is still small, it is a profession that stands ready to help industry and society. I'm sure that the sessions that follow will show you some of the ways in which that is done.

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Van Cott, H.P. & Kinkade, R.G. (Eds.). Human Engineering Guide to Equipment Design. New York, N.Y.: McGraw-Hill, 1972.

HUMAN FACTORS ASPECTS OF CONTROL ROOM DESIGN

MR. JAMES P. JENKINS
HUMAN FACTORS BRANCH
OFFICE OF NUCLEAR REGULATORY
RESEARCH COMMISSION

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HUMAN FACTORS ASPECTS OF CONTROL ROOM DESIGN

The U.S. Nuclear Regulatory Commission (NRC) has been active in the area of human factors in control rooms, particularly in recent years. I am going to present for you a plan for the design, analysis, and review of multistation control rooms. Many benfits will accrue to the users of the control room as a consequence of human factors applications.

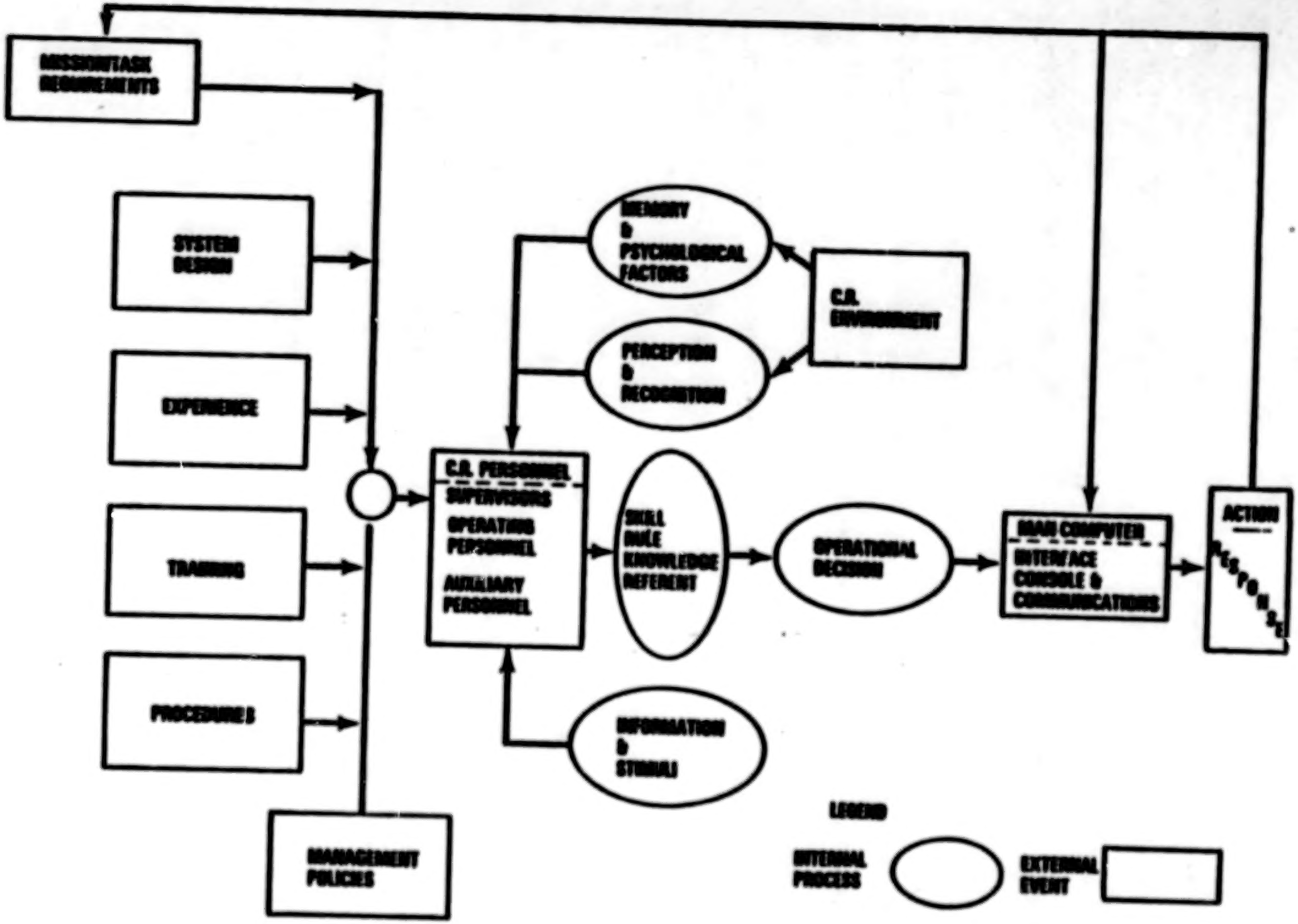
Human factors at NASA is not a recent event and I call to mind such notables as Jack Kraft and Stan Deutsch and others who have contributed significantly to the design of current systems and prior space flight systems. So I'm very conscious that NASA's management and staff are serious users of human factors.

When we talk about control rooms, we ask, "What are the human factors problems involved?" The following list is a classification of the problems usually encountered:

- System Related Problems
- Operator Related Problems
- Procedures Based Problems
- Information Related Factors
- Operational Related Factors - tasks to be performed to achieve mission success
- The Problem of the Criterion and Methods of Measurement - How do we know the phenomena being studies is really a problem? How do we assess it?

Figure 1 shows the dynamics involved in a typical nuclear control room. Generally, licensed operators supervise and control the operations of a plant from cold shut down through 100 percent power operation and back to cold shut down for all design-based accident conditions. A design-based accident is an accident which the plant has been designed to cope with effectively.

The physical layout of a control room is fairly standard. Typically, at the center of the control room, you will see a presentation or a picture of the control rods of the


MISSION/TASK REQUIREMENTS
SYSTEM DESIGN
EXPERIENCE
TRAINING
PROCEDURES
MANAGEMENT POLICIES
C.R. PERSONNEL
SUPERVISORS
OPERATING PERSONNEL
AUXILIARY PERSONNEL
MEMORY & PSYCHOLOGICAL FACTORS
PERCEPTION & RECOGNITION
C.R. ENVIRONMENT
SKILL RULE KNOWLEDGE REFERENT
OPERATIONAL DECISION
MAN COMPUTER
INTERFACE CONSOLE & COMMUNICATIONS
ACTION
RESPONSE
INFORMATION & STIMULI
LEGEND
INTERNAL PROCESS
EXTERNAL EVENT

CONTROL ROOM DYNAMICS

FIGURE 1

reactor, which is a system status indicator that allows you to know rod status. Also you have a large number of conventional-design displays and controls. Some control rooms have CRT database information systems, others do not. It's a large room; tests are always going on; maintenance activities may be checked during plant operation. The plant is responsive for the production of electricity, and you may have electrical demand that might cause it to increase or decrease its power output. But typically, once a plant is brought up to full power, management seeks to maintain a constant power level. Typically, at the top of a control room, you see a large number of annunciators. These are backlit legends, each with very cryptic information. They illuminate only when an event occurs or, to show the status of a condition.

HUMAN FACTORS PROBLEMS

Let us consider some of the problems that we have encountered in control rooms. One problem concerns where the supervisor should be. If we have many feet of displays and controls, a central supervisor's station would seem like a good idea; it is not. Sometimes a desk is placed in the center and other times it's a general area where the documentation, as well as the telephone communications, are available. The key is a task analysis and link analysis. At NASA you will likely have in some of your control rooms an amalgamation of older technology and new technology that you want to integrate. The role and functions of a supervisor, as well as his/her physical station or locus of control, should be considered early in the design phase.

Another significant problem is packing data on an annunciator tile. If you must use annunciators, consider the problem of reading. Typically, a nuclear power plant control room will have 1200 to over 2500 tiles. The operators attempt to memorize all those tiles, so that by looking at the whole, they can identify the actual problem: "Well, when I see this configuration, that means such and so", rather than actually reading what is presented. This may be a significant source of error and human factors problems.

One can also have a problem with visual access to displays. Some systems are designed independently and, when they are placed together, they don't fit the workspace properly. Sometimes, protruding units obstruct an operator's view. Thus an operator must stand or sit at an awkard angle for adequate visibility. Another example illustrates poor placement of equipment; an operator using a computer-based terminal must leave the station, walk around the corner to look at the printer, and remember what he has seen when he gets back to his station. Another visual problem is glare on CRT screens from poorly designed illumination sources. This glare may wipe out usable visual data.

Color coding has been an attempt to distinguish important events. Often their relationships are not one to one with the controls. If colors are used they must be consistent and meaningful among and between displays and controls. Other problems relate to control design and legends.

Often operators will compensate for critical values which should have been preprinted. For example, there is the famous picture of two large beer handles attached to tiny switches so the operator had ready access to them because of their importance. Also labels have been attached to control boards when no sensible relationship is seen between and among the controls. Operators may be called on to memorize the relationship and, in the heat of an incident, this may constitute a mental load that is a source of error.

One final consideration is the maintenance station. It is not in the control room but operators use it to do special tests. When you design equipment for testing, have the same care for human factors as you would for your main panel. Do not make it an unnecessarily complicated system.

These are our kinds of problems. What do we do about them? We do not control, as you do, the design of control rooms. We are regulators, and that's a very different kind of position to be in—for human factors people to write standards, guidelines, and regulations.

To refresh your minds again—we have system problems, operator-related problems, procedure-information related, and operational-related problems. And we, as human factors people, have the problem of how to measure, and how to evaluate. What are some of the human factors potential solutions (Figure 2)?

HUMAN FACTORS SOLUTIONS

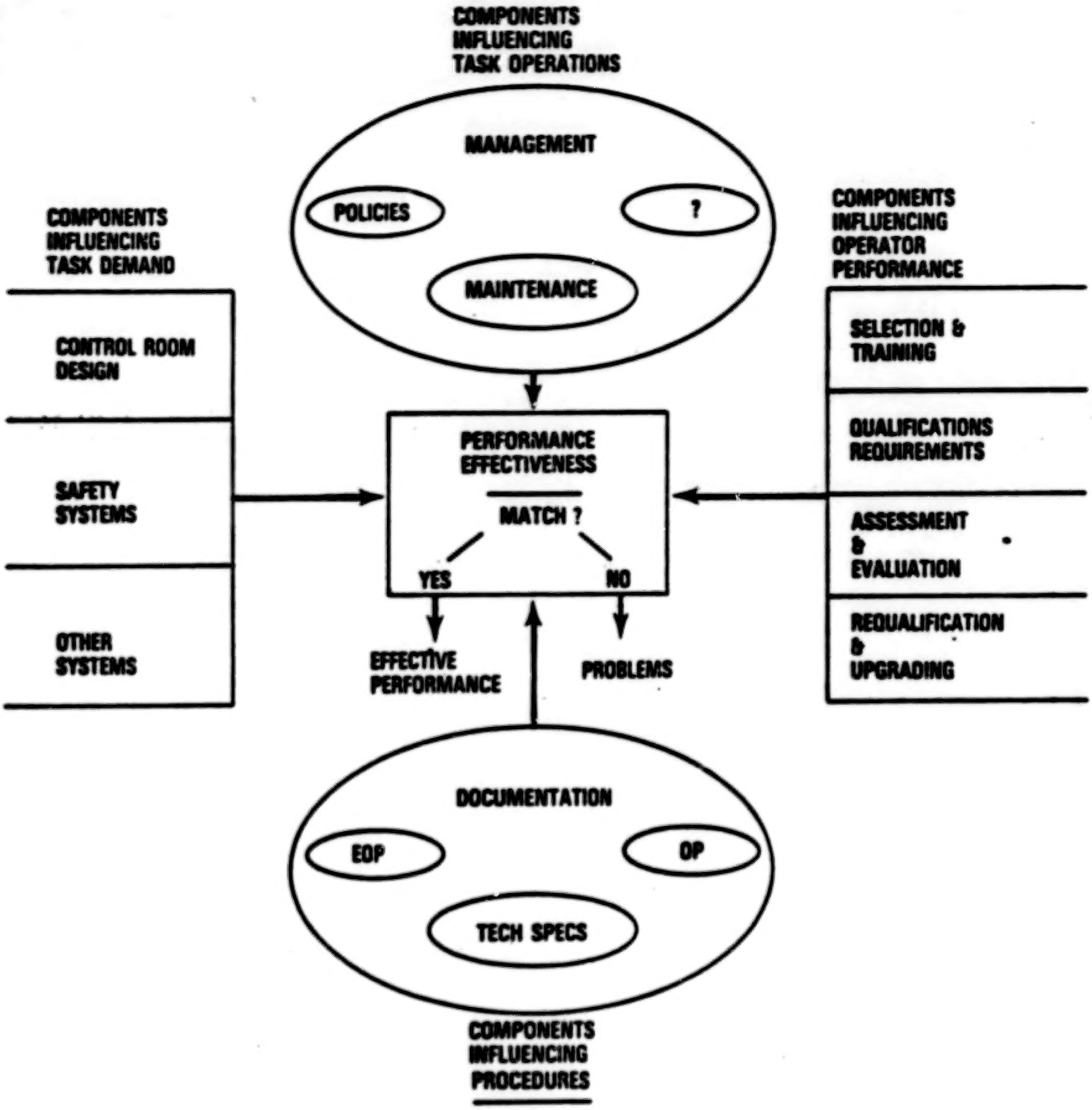
In order to describe, plan, and predict what your approach will be and to evaluate the priorities, I present a man-machine model (Figure 3). There are a variety of components which influence the task demand; that is, they can increase or decrease the probability of successful task completion. We are very concerned with the safety systems, since one of our missions is the health and safety of the public. There are other systems which interact with the safety systems which also influence the task demand. There are components which influence the operations, management, and the policies which management prepares, and the maintenance practices which affect the task to be performed. How available is your system? Do you have a high reliability system for your needs? What components influence the operator's performance, such as selection and training? Are the key personnel nearly equal in terms of minimum qualifications? The assessment and evaluation methods which the manager uses affects operator performance. The requalifications and upgrading of people must be considered. You are not going to have someone take a job in the control room and always remain at that level; they will want to advance. You've heard of Maslow's hierarchy of needs; they want to satisfy those kinds of needs.

I think there are more human error and human problems related to procedures than there are to the kinds of problems found in human engineering. You have components influencing procedures. Operators are going to have to be dependent on the procedure based information. These include normal and emergency operating procedures, and technical specifications.

CONTROL ROOMS - WHAT ARE HUMAN FACTORS SOLUTIONS?

- MAN-MACHINE MODEL TO DESCRIBE, PLAN AND PREDICT
- SYSTEMS ANALYSIS
- ALLOCATION OF FUNCTIONS
- JOB/TASK ANALYSES
- HUMAN FACTORS ENGINEERING APPLICATIONS
- SYSTEMS INTEGRATION
- SYSTEMS TESTING AND VERIFICATION
- CONTROL ROOM DESIGN REVIEW
- OPERATOR/USER ACCEPTANCE

FIGURE 2


COMPONENTS INFLUENCING TASK OPERATIONS
MANAGEMENT
POLICIES
?
MAINTENANCE
COMPONENTS INFLUENCING TASK DEMAND
CONTROL ROOM DESIGN
SAFETY SYSTEMS
OTHER SYSTEMS
COMPONENTS INFLUENCING OPERATOR PERFORMANCE
SELECTION & TRAINING
QUALIFICATIONS REQUIREMENTS
ASSESSMENT & EVALUATION
REQUALIFICATION & UPGRADING
PERFORMANCE EFFECTIVENESS
MATCH ?
YES
NO
EFFECTIVE PERFORMANCE
PROBLEMS
DOCUMENTATION
EOP
OP
TECH SPECS
COMPONENTS INFLUENCING PROCEDURES

CONTROL ROOM MAN-COMPUTER MODEL

FIGURE 3A

CONTROL ROOM MAN - COMPUTER EFFECTIVENESS

A MODEL

- COMPONENTS INFLUENCING TASK DEMAND: MEASURES OF DESIGN RELATED FACTORS
- COMPONENTS INFLUENCING TASK OPERATIONS: MEASURES OF LIMITING FACTORS WHICH COULD DETRACT FROM OVERALL EFFECTIVENESS
- COMPONENTS INFLUENCING OPERATOR PERFORMANCE: PERSONAL AND PERSONNEL CONSEQUENCES AFFECTING INDIVIDUAL PERFORMANCE EFFECTIVENESS
- COMPONENTS INFLUENCING PROCEDURES: MEASURES OF SOFTWARE AND METHODS ADEQUACY

IS THERE A MATCH??

WHAT IS THE VARIABILITY??

DOES IT MAKE A DIFFERENCE??

HOW LARGE A DIFFERENCE??

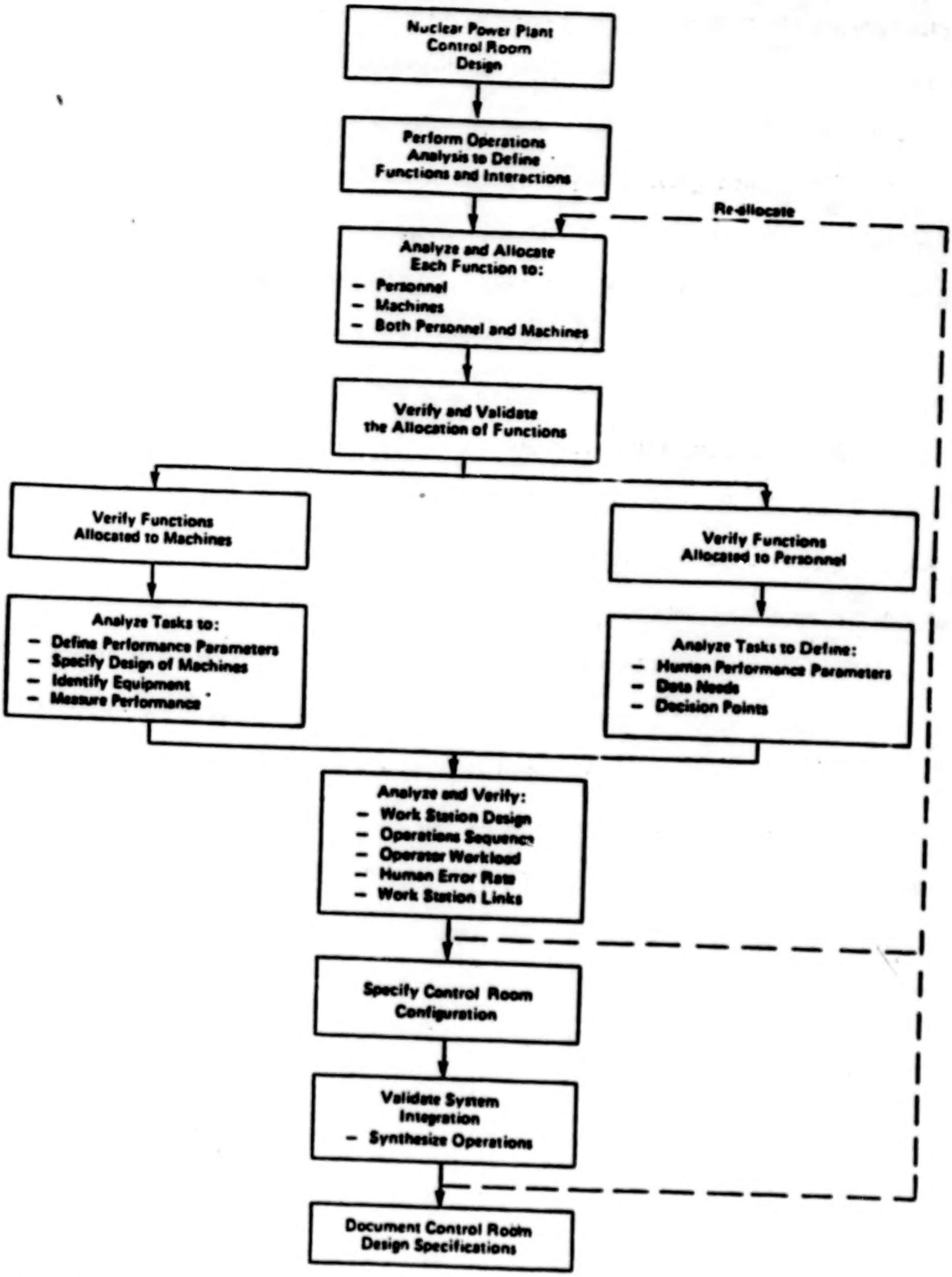
FIGURE 3B

All of these components come together and you ask the questions, "Do I have performance effectiveness? Do I have a match?" If I do, then I have effective performance. If I don't, I have a number of problems. Perhaps you want to evaluate or design your own model; to begin, you would develop a model of the system to identify the major components of variance—the things that make a real difference. You will use the model to help you plan your own direction and your own activities to look at alternate designs and finally to evaluate how well you have achieved the design.

The use of systems analysis is extremely important. This is a structure for function analysis, allocation, verification, and validation. A control room design is intended to perform certain kinds of operations. The human factors and systems analysts people identify the functions and their interactions within the control room. Through this analysis, we verify and validate the allocation of functions; look at performance parameters, including the equipment design; and measure performance on these factors. Review your human performance parameters, data needs, and decision points. Place them in the work station. Consider the operational sequence workload, the error rate, and the work station lengths. Reconsider the whole process if you identify problems there. Ultimately you will arrive at some specified control room configuration. These human factors solutions are enumerated in Figure 2. You design, build and then validate the integration of the control room with the entire operations and document it. That is a process which you use when you are starting out with simply a design requirement and a mission requirement. On the other hand, you might be dealing with already existing control rooms and you do not have the luxury of starting out from scratch. We'll look at both processes in detail now.

APPLICATIONS TO THE DESIGN OF NEW CONTROL ROOMS

For new control rooms, we begin with a function analysis (Figure 4). A function analysis or function allocation is the assignment of a function to an operator, technician, equipment, computer hardware, software or combinations of these based on a comparison


Nuclear Power Plant Control Room Design
Perform Operations Analysis to Define Functions and Interactions
Re-allocate
Analyze and Allocate Each Function to:
– Personnel
– Machines
– Both Personnel and Machines
Verify and Validate the Allocation of Functions
Verify Functions Allocated to Machines
Verify Functions Allocated to Personnel
Analyze Tasks to:
– Define Performance Parameters
– Specify Design of Machines
– Identify Equipment
– Measure Performance
Analyze Tasks to Define:
– Human Performance Parameters
– Data Needs
– Decision Points
Analyze and Verify:
– Work Station Design
– Operations Sequence
– Operator Workload
– Human Error Rate
– Work Station Links
Specify Control Room Configuration
Validate System Integration
– Synthesize Operations
Document Control Room Design Specifications

STRUCTURE FOR FUNCTION ANALYSIS, ALLOCATION, VERIFICATION AND VALIDATION

FIGURE 4

of their capabilities and limitations to perform the function. It can answer such questions as: What is the hierarchy of functions? You have to recognize there are, in fact, a hierarchy of functions that approximate the best solution. What is the organization of the components, the man/machine system components that are needed to achieve the mission goals or the common goals for which you need a man/machine system? What are the proper actions that the system control rooms takes to meet those goals? What criteria should be used to evaluate the performance of these functions?

Do we have criteria well established? Do we know that we can apply to every human or every man/machine function good standards, and good metrics of performance? In fact, the human factors staff that you would use might well spend a considerable time in identifying the appropriate criteria to evaluate your systems. A function analysis is the starting place to answer these kinds of questions in the beginnning of a new design.

How do you validate and verify your function allocation? You want to do it to establish that the human can perform all the assigned functions and tasks for the specified control room design. You seek to verify that the product of each step in the development of the design specifications fulfills the requirements. It's a process-not a one time event, a process to ensure compliance of the design specifications with the integrated functional and performance requirements of the control room. Validation in the classical sense that human factors psychologists use is a congruency between the phenomena that you observed and some underlying construct. The following techniques are useful for system verification and validation:

> Simulations and modelling. I would urge you to consider simulations as a very cheap and effective tool for system evaluation. There are already existing software that can be applied to systems which in fact have been verified as rather predictive of man/machine performance.
>
> Field trials and in-situ observations. They frequently are difficult to identify exactly the dependent variable, that which you are trying to measure with all of the other events that are happening in the real control room, but nevertheless you can get some good insights especially with repeated observations to get some reliability in your observations by the naturalistic setting.

Workload analysis of physical and cognitive activities are possible. New techniques are being developed rather frequently and I'm sure a number of specific techniques are applicable for your situation.

Human error analysis and probablistic risk assessment. This, perhaps, is more unique to the nuclear part of the industry than to NASA, but to put human error in terms of overall probable systems performance capabilities allows you to do tradeoffs between system design and known sources of human error or to pinpoint where you want to maximize your return or your investment so far as a probablistic solution is concerned. These methods can be used for verification and validation.

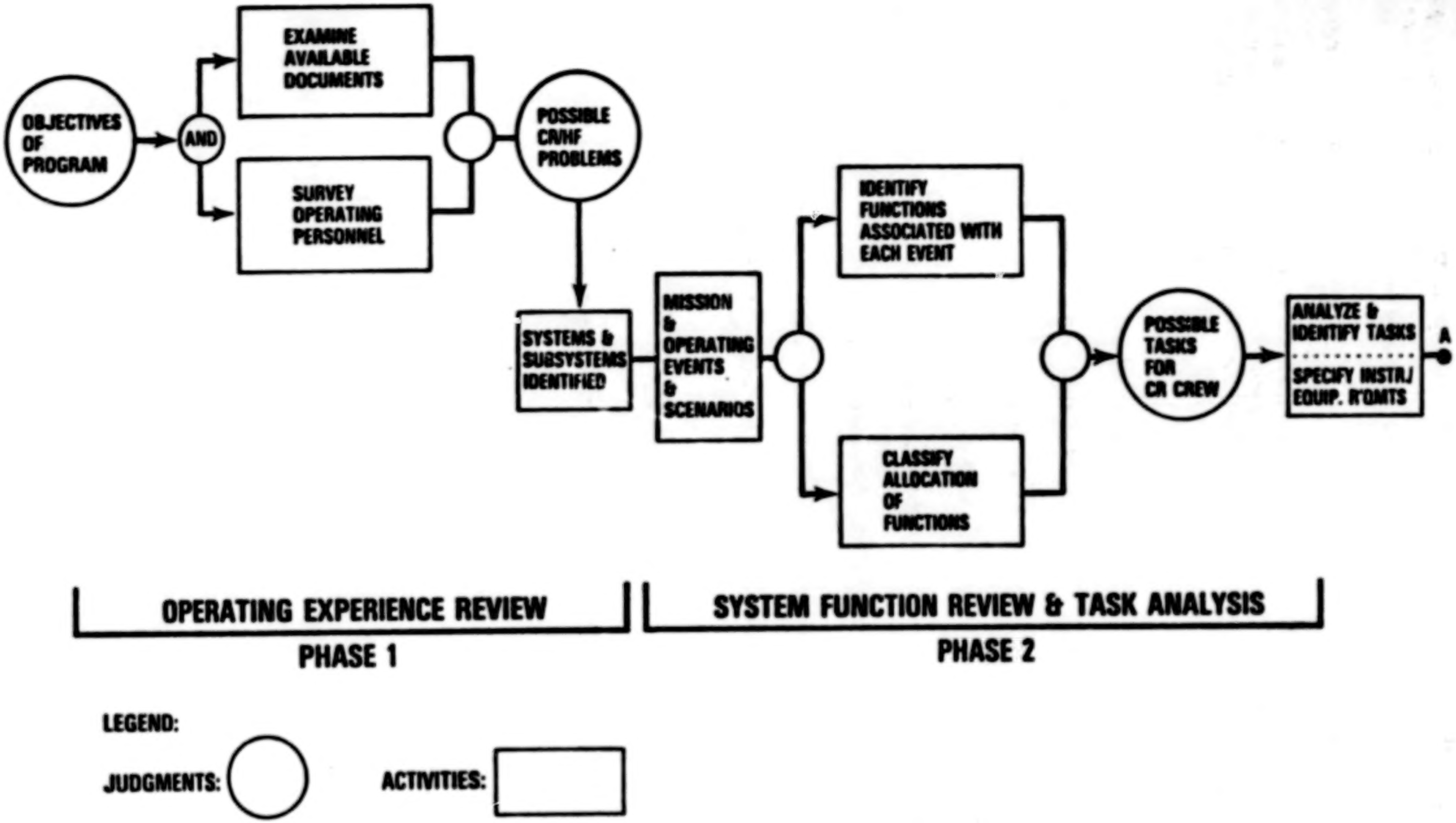
EXISTING CONTROL ROOMS

For existing control rooms the following list presents 6 phases of analysis in use at NRC for something called a control room review.

- Phase 1: Operating experience review
- Phase 2: System function review and task analysis
- Phase 3: Control room survey and inventory
- Phase 4: Verification of capabilities
- Phase 5: Validation of control room functions and integrated performance capabilities
- Phase 6: Selection of design corrections

Phase 1 of the process identifies the objectives of the control room review (Figure 5). What specific information is needed? What procedures have they used? We interview the operating people, look at the documentation and from it, come out with possible control room human factors problems.

At the same time we identify the basic systems and subsystems and the scenarios which those systems and subsystems are used for as they truly exist. This tells us what are the priority activities of that control room and we can then look at the functions associated with each event and classify the allocations of functions which must have occurred in order for the system to operate. It's a retrospective analysis. From both of these we identify the possible tasks that the crew likely performs. We do a retrospective task analysis. When you are designing a new control room, you do a task analysis based


OBJECTIVES OF PROGRAM
AND
EXAMINE AVAILABLE DOCUMENTS
SURVEY OPERATING PERSONNEL
POSSIBLE CR/HF PROBLEMS
SYSTEMS & SUBSYSTEMS IDENTIFIED
MISSION & OPERATING EVENTS & SCENARIOS
IDENTIFY FUNCTIONS ASSOCIATED WITH EACH EVENT
CLASSIFY ALLOCATION OF FUNCTIONS
POSSIBLE TASKS FOR CR CREW
ANALYZE & IDENTIFY TASKS
SPECIFY INSTR./ EQUIP. R'QMTS
A
OPERATING EXPERIENCE REVIEW
PHASE 1
SYSTEM FUNCTION REVIEW & TASK ANALYSIS
PHASE 2
LEGEND:
JUDGMENTS:
ACTIVITIES:

REVIEW PROCESS OF CONTROL ROOMS

FIGURE 5

BEST DOCUMENT AVAILABLE

on mission requirements. We do a task analysis here, based on the way the system already operates. From the task analysis, we identify the specific information requirements. The operating experience review, system-function review, and task analysis identify the way the system operates, the tasks the crew perform, and gives insight into the likely human factors problems. Parenthetically, the human engineering problems in controls and displays may or may not be important and this is one way of assessing the degree of importance that a poor design might have.

In the next phase, we conduct an inventory of the equipment and instruments to identify the design basis. The range, the accuracy, the speed of response, the particular characteristics of the equipment and instrumentation are catalogued. We can compare that inventory with the initial documentation to determine what changes have been made. At the same time, we do a survey of the control room to determine its conformance with conventional human factors engineering guidelines and standards (Figure 6). We document these by photographs, to determine how that control room meets acceptable human factors standards. From these photos, we get human engineering discrepancies and possible problems. The discrepancies are real; the problems may or may not be real. We are still open to judgment on these. In the verification of capabilities phase, we compare the personnel performance task and hardware requirements in the inventory with the people and come out with possible equipment problems and possible task problems.

At this point, we have viewed the existing control room design from an objective point of view. Now we walk through and talk through with the crew for the critical events (Figure 7). A talk through is sitting down with some operators of the system for missions they are familiar with, and ask them to describe what they do. A walk through is a process in which we take the procedures and walk through the tasks the crew does, such as the controls, the displays, the data, and the decision made for those missions. We also have tried real-time simulations. We use video tape recordings and ask the crew to

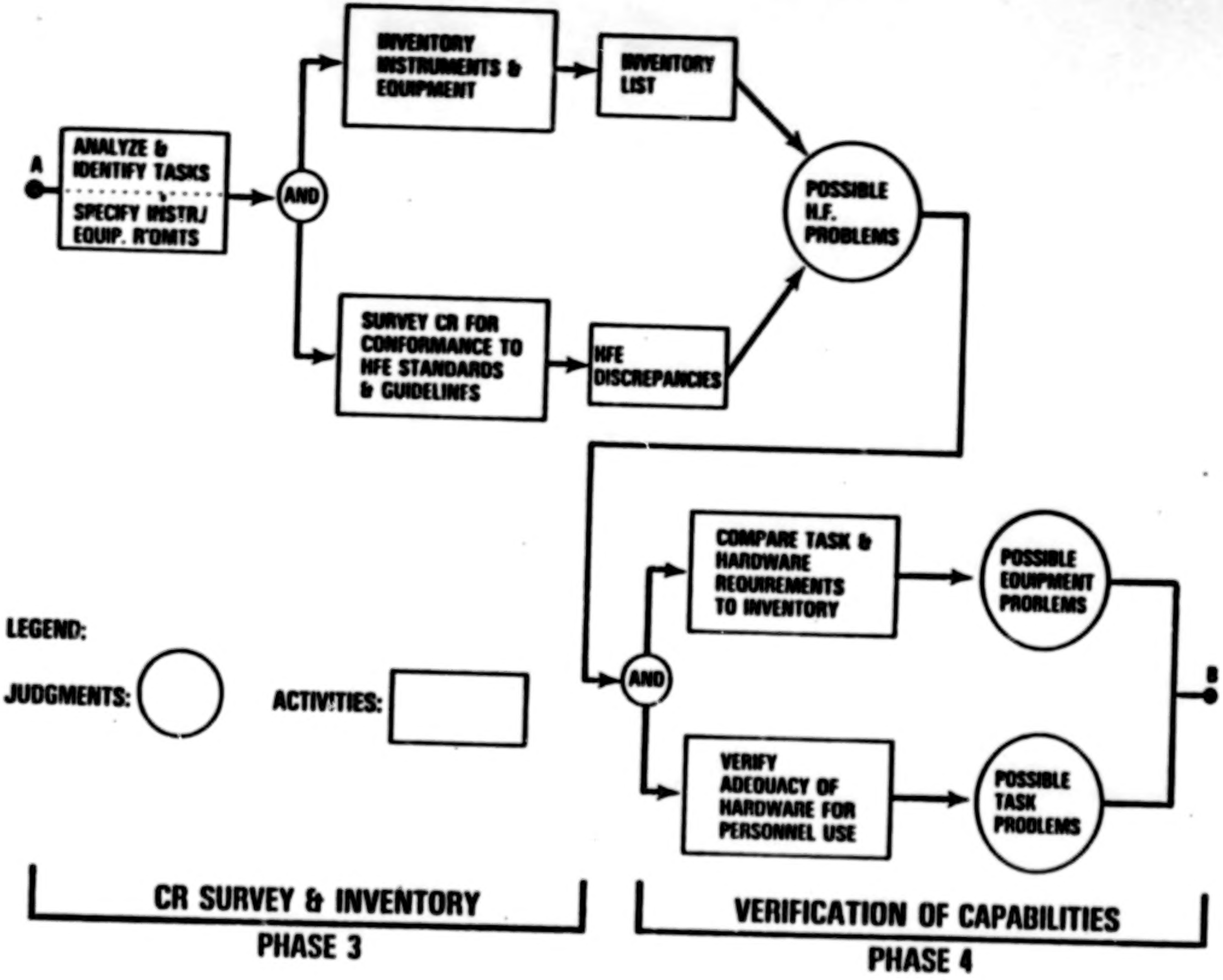
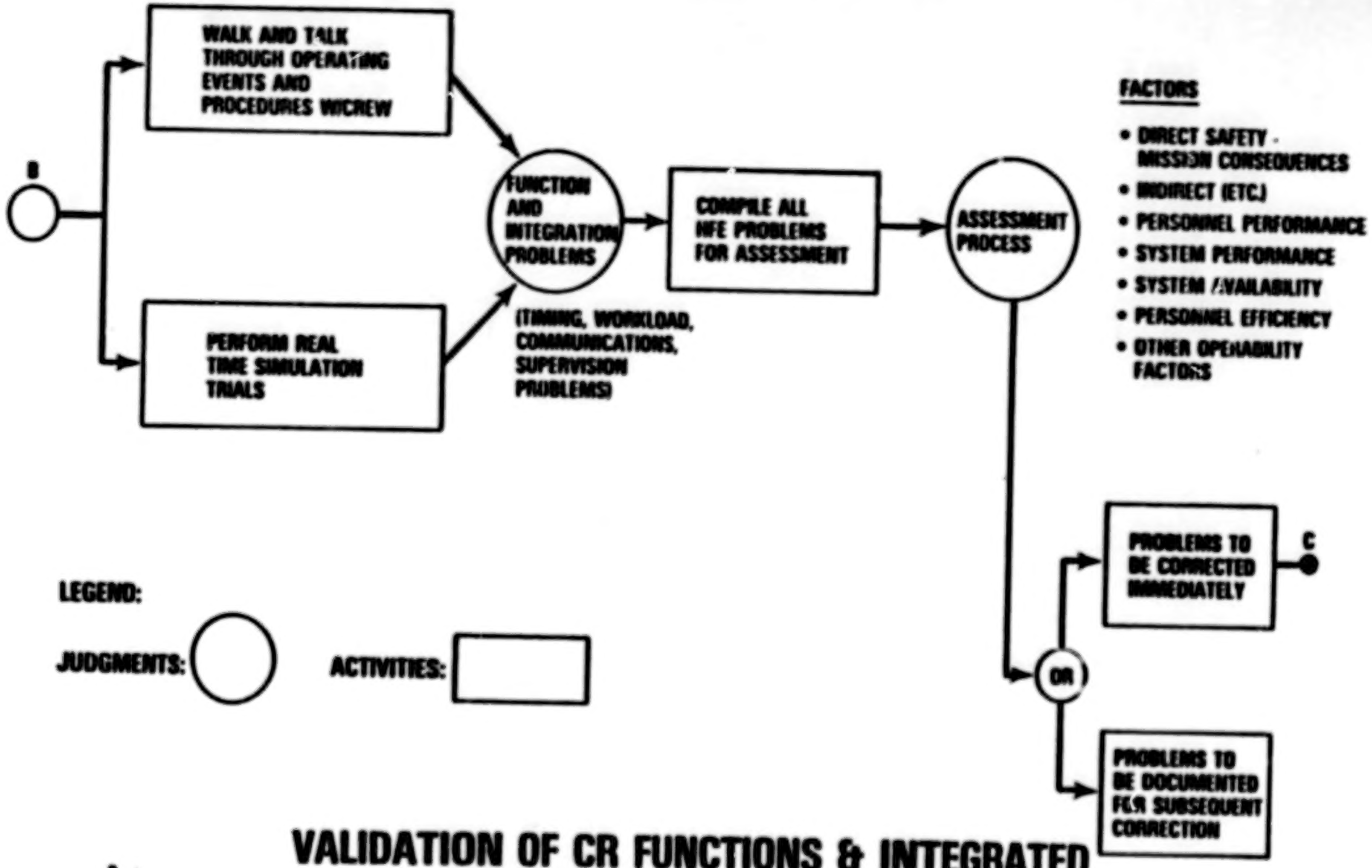

A
ANALYZE & IDENTIFY TASKS
SPECIFY INSTR/ EQUIP. R'QMTS
AND
INVENTORY INSTRUMENTS & EQUIPMENT
INVENTORY LIST
SURVEY CR FOR CONFORMANCE TO HFE STANDARDS & GUIDELINES
HFE DISCREPANCIES
POSSIBLE H.F. PROBLEMS
AND
COMPARE TASK & HARDWARE REQUIREMENTS TO INVENTORY
POSSIBLE EQUIPMENT PROBLEMS
VERIFY ADEQUACY OF HARDWARE FOR PERSONNEL USE
POSSIBLE TASK PROBLEMS
B
LEGEND:
JUDGMENTS:
ACTIVITIES:
CR SURVEY & INVENTORY
PHASE 3
VERIFICATION OF CAPABILITIES
PHASE 4

FIGURE 6


B
WALK AND TALK THROUGH OPERATING EVENTS AND PROCEDURES W/CREW
PERFORM REAL TIME SIMULATION TRIALS
FUNCTION AND INTEGRATION PROBLEMS
(TIMING, WORKLOAD, COMMUNICATIONS, SUPERVISION PROBLEMS)
COMPILE ALL HFE PROBLEMS FOR ASSESSMENT
ASSESSMENT PROCESS
FACTORS
• DIRECT SAFETY - MISSION CONSEQUENCES
• INDIRECT (ETC.)
• PERSONNEL PERFORMANCE
• SYSTEM PERFORMANCE
• SYSTEM AVAILABILITY
• PERSONNEL EFFICIENCY
• OTHER OPERABILITY FACTORS
OR
PROBLEMS TO BE CORRECTED IMMEDIATELY
C
PROBLEMS TO BE DOCUMENTED FOR SUBSEQUENT CORRECTION
LEGEND:
JUDGMENTS:
ACTIVITIES:

VALIDATION OF CR FUNCTIONS & INTEGRATED PERFORMANCE CAPABILITIES

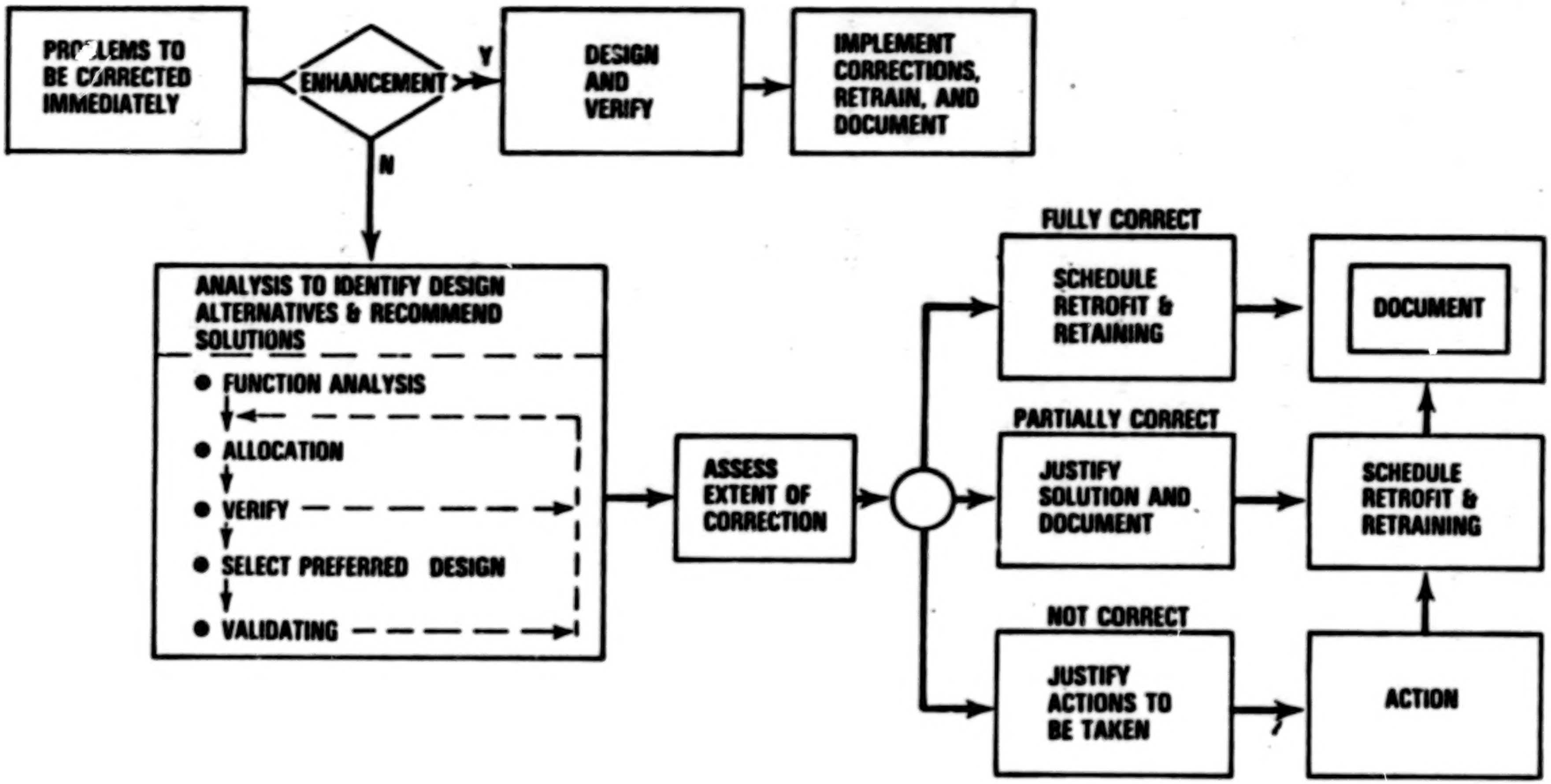
PHASE 5

FIGURE 7

go through the steps in the task. We configure the system either on the simulator or in the actual control room, to represent that particular mission's conditions. We film it for later analysis because we have found that a crew will forget that they do certain things when we talk through or walk through this mission. They might accidently miss something, but when they are using their own procedures, we capture on film those events actually performed.

At phase 5 we coalesce the total system. We compile all our problems in an assessment and we look at the factors (Figure 5). This allows the identification of real problem areas. These are reviewed for their mission consequences or indirect consequences: personnel performance and systems requirements; the availability of personnel and the system to respond to problems; and other operability factors as they exist. From this, we identify problems to be corrected immediately, or those to be documented for subsequent correction.

The last phase is the correction of problems (Figure 8). For those problems to be corrected immediately, we ask the question, "Do we want to correct the problem and further enhance the control room to make it better?" This is a decision point. If we do want to enhance a system, we basically go through a redesign process. If the decision is not to perform an enhancement but simply to correct the problem, we analyze design alternatives and recommend solutions. We go through a function analysis, allocation verification, select the preferred design, validate it, and reiterate that process until we know how well we can correct the problem. The problem is not always 100 percent corrected. If it's fully corrected, we look at a schedule for retrofit and retraining of the personnel and document it. If it's partially corrected, we justify the solution, document it, retrain, and reschedule, if necessary. If the decision is made not to correct, we justify the action to be taken and document it. That's the methodology we use for a human factors analysis of existing control rooms.


PROBLEMS TO BE CORRECTED IMMEDIATELY
ENHANCEMENT
Y
N
DESIGN AND VERIFY
IMPLEMENT CORRECTIONS, RETRAIN, AND DOCUMENT
ANALYSIS TO IDENTIFY DESIGN ALTERNATIVES & RECOMMEND SOLUTIONS
● FUNCTION ANALYSIS
● ALLOCATION
● VERIFY
● SELECT PREFERRED DESIGN
● VALIDATING
ASSESS EXTENT OF CORRECTION
FULLY CORRECT
SCHEDULE RETROFIT & RETAINING
DOCUMENT
PARTIALLY CORRECT
JUSTIFY SOLUTION AND DOCUMENT
SCHEDULE RETROFIT & RETRAINING
NOT CORRECT
JUSTIFY ACTIONS TO BE TAKEN
ACTION

SELECTION OF DESIGN CORRECTIONS

PHASE 6

FIGURE 8

Thus far, I really haven't said much about man/computer interaction because it has been intregal throughout this entire process. Whether you have a dedicated computer or a process computer, there are some special considerations to incorporate when it comes to the use of computer-based aids in existing control rooms—that is, you are retrofitting into an existing control room a completely new concept in data management and information.

We have found that many computers-based systems fail to meet their performance requirements because the design of the man/machine interface is really inadequate. The issue of acceptance of the computer-based information system by the user in the control room is mandatory for mission and system success. A list of criteria to improve computer/user interface include:

- Match of system input/output with user
- Reliability, compatibility and maintainability—maximum of 5 seconds for feedback from human input.
- Easy to learn and little training needed
- Self descriptive system
- System under user control
- Transparent language, format and organization—i.e., user friendly.
- Corresponds to user exprectations
- Adaptable to user experience level
- Fault tolerant-operator can make mistakes
- Has dialog capability-user communications needs reflected in flexibility, complexity, power and information load
- Integrated system
- Documentation—willingness to pay for good documentation will pay off in the long run.

The last figure is a list of the basic references useful for control room reviews (Figure 9). Many other references are contained in the document, Guidelines for Control Room Design Reviews, NUREG 0700. It can be obtained from the NRC in Washington,D.C.

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Figure 9

DESIGN OF INTERACTIVE SYSTEMS

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COMPUTER SCIENCE DEPARTMENT
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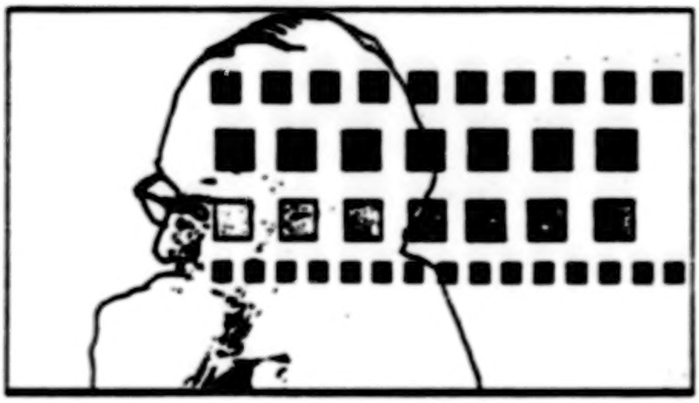
Dr. Ben Shneiderman has submitted the following paper for inclusion in the NASA proceedings. This paper formed the basis of his presentation. The viewgraphs used during his talk follow.



Human Factors Experiments in Designing Interactive Systems

Ben Shneiderman
University of Maryland

Providing useful tools for computer users with a wide range of experience, problems, skills, and expectations is a challenge to scientific competence, engineering ingenuity, and artistic elegance. System developers are increasingly aware that ad hoc design processes, based on intuition and limited experience, may have been adequate for early programming languages and applications but are insufficient for interactive systems which will be used by millions of diverse people. Regular users quickly pass through the gadget fascination stage and become demanding users who expect the system to help them in performance of their work. Clearly, therefore, interactive computer-based consumer products for home, personal, or office applications require increasing levels of design effort.

Unfortunately, it is not possible to offer an algorithm for optimal or even satisfactory design. Interactive system designers, like architects or industrial designers, seek a workable compromise between conflicting design goals. Systems should be simple but powerful, easy to learn but appealing to experienced users, and facilitate error handling but allow freedom of expression. All of this should be accomplished in the shortest possible development time, costs should be kept low, and future modification should be simple. Finding a smooth path through these conflicting goals is a challenge.

Henry Dreyfuss,[1] a leading industrial designer responsible for plane, train, and boat interiors as well as dozens of familiar consumer items, provides useful guidance. He devotes a full chapter to the experience of designing the 500-Type Telephone, the standard rotary dial desk model. Measurements of 2000 human faces were used to determine the spacing between the mouth and ear pieces. After consultation with Bell System engineers about the layout of electronic components, 2500 sketches for possible designs were made. Numerous variations of the handgrip were considered until the familiar rounded-off rectangular cross section was adopted. Variations on dial and faceplate were tested until a 4¼-inch diameter faceplate was selected to replace the older 3-inch version. Placement of the letters and numbers was studied, the angle of the dial was adjusted to reduce glare, and the cradle was modified to minimize the receiver-off-the-hook problem. Accurate layout drawings were made for all the variations, and finally clay and plaster models were built to compare the leading designs. Then testing began.

This process contrasts sharply with most interactive system development experiences where designs are hastily proposed and evaluated informally. Alternative command structures, error handling procedures, or screen formats rarely get implemented for pilot testing purposes. Dreyfuss spends another entire chapter emphasizing the importance of testing. Tests and pilot studies should be more than the informal, biased opinion of a colleague. A pilot test should involve actual users for sufficient time periods to get past initial learning problems and novelty. Conflicting designs should be evaluated in carefully controlled experimental conditions. Though experiments provide no guarantee of quality, they are far better than informal guesswork. The process of developing an experimental comparison can itself be productive, often providing worthwhile insights. Statistical performance data and informal subjective commentary from participants can be valuable in fine-tuning proposed procedures. Experimental research can lead to fundamental insights which transcend specific systems. Nickerson,[2] Bennett,[3] Martin,[4] and Miller and Thomas[5] provide broad-ranging reviews of issues and references for designers and researchers of interactive systems. Shneiderman[6] covers related work in data-base facilities, and other articles in this issue focus on programming language usage.

0018-9162/79/1200-0050$00.75 © 1979 IEEE COMPUTER Vol. 12, No 12

Goals for interactive system designers

The diversity of situations in which interactive systems may be used makes it difficult to prescribe a universal set of goals. The attempts of several system designers to define goals are shown in Figures 1 through 8.

Foley and Wallace[15] make their recommendations by enumerating five problem areas: boredom (improper pacing), panic (unexpectedly long delays), frustration (inability to convey intentions or inflexible and unforgiving system), confusion (excessive detail or lack of structure), and discomfort (inappropriate physical environment).

The best detailed guide for design of interactive display systems was developed by Engel and Granda.[16] They make specific suggestions about display formats, frame contents, command language, recovery procedures, user entry techniques, general principles, and response time requirements.

Unfortunately, these lists are only crude guides to the designer. The entries are not independent and sometimes are in conflict. The lists contain contradictory recommendations and are certainly incomplete. Finally, these design goals are largely unmeasurable. Can we assign a numerical value to the simplicity, stability, responsiveness, variety, etc., of a system? How can we compare the simplicity of two design proposals? How do we know what has been left out of the system design?

Experimental research can help to resolve some of these issues and refine our capacity to measure system quality. Still, some aspects of designing will remain an art or intuitive science where esthetics and contemporary style determine success.

The remainder of this paper presents several human factors issues in designing interactive systems. The discussion is independent of hardware-related concerns such as the design of keyboards, displays, cursor controls, audio output, speech recognition, graphics systems, and customized devices, and software-related topics such as natural language front-ends, menu selection, command languages, data-base query facilities, and editors. The emphasis is on general problems and basic experimental results.

Attitude and anxiety

Several studies have demonstrated that user attitudes can dramatically affect learning and performance with interactive systems. Walther and O'Neil,[17] for example, showed that novices with negative attitudes towards computers learned editing tasks more slowly and made more errors. Anxiety, generated by fear of failure, may reduce short-term memory capacity and inhibit performance. If users are insecure about their ability to use

First principle: Know the user

Minimize memorization
  Selection not entry
  Names not numbers
  Predictable behavior
  Access to system information

Optimized operations
  Rapid execution of common operations
  Display inertia
  Muscle memory
  Reorganize command parameters

Engineer for errors
  Good error messages
  Engineer out the common errors
  Reversible actions
  Redundancy
  Data structure integrity

Figure 1. User engineering principles for interactive systems (W. J. Hansen, 1971).[7] Hansen's First Principle should be the motto of every designer: Know the User. No qualifier or explanation is necessary. Hansen's sensitivity to human short-term memory limitations leads to his second category: minimizing memorization. Under "optimization of operations," Hansen includes "display inertia," suggesting that when operations are applied, as little of the display should be changed as possible. This approach reduces disruptive movement and highlights the impact of the last operation. "Muscle memory" refers to the idea that users develop the feel for frequently used keypresses. Hansen recognizes the importance of engineering for errors by providing good error messages, reversible actions, and revisions to engineer out common errors.

1. Provide a program action for every possible type of user input.
2. Minimize the need for the user to learn about the computer system.
3. Provide a large number of explicit diagnostics, along with extensive on-line user assistance.
4. Provide program shortcuts for knowledgeable users.
5. Allow the user to express the same message in more than one way.

Figure 2. The design of idiot-proof interactive programs (A. I. Wasserman, 1973).[8] Wasserman's five design principles are reasonable, but the second and fifth ones may need qualification. Although it is usually good to minimize the user's need to learn about the computer system, restricting access to those who have acquired a certain knowledge level may sometimes be a good idea. The qualifying test, which works well for driver's licensing and college entrance, may be useful for complex and powerful systems. Naive users should be prevented from using a system which is too hard for them and would produce an unpleasant experience. Wasserman's fifth principle may not always be good advice. Novices will prefer and do better with a system which has few choices and permits only limited forms of expression.

the system, worried about destroying files or the computer itself, overwhelmed by volumes of details or pressured to work rapidly, their anxiety will lower performance. Programmers who must meet a deadline tend to make more errors as they frantically patch programs in a manic attempt to finish. Of course, mild pressure can act as a motivator, but if the pressure becomes too strong the resultant high levels of anxiety interfere with competent work.

In designing a system for novices, every attempt should be made to make the user at ease, without being patronizing or too obvious. A message telling users not to be nervous is a bad idea. Users will feel best if the instructions are lucid, in familiar terms, and easy to follow. They should be given simple tasks and gain the confidence that comes with successful use of any tool or machine. Diagnostic messages should be understandable, nonthreatening, and low-key. If the imput is incorrect, avoid blaring phrases such as "ERROR 435—NUMBERS ARE ILLEGAL" and merely state what is necessary to make things right—e.g., "MONTHS ARE ENTERED BY NAME." Try to avoid meaningless, condemning

1. Know the user population.
2. Respond consistently and clearly.
3. Carry forward a representation of the user's knowledge basis.
4. Adapt wordiness to user needs.
5. Provide the users with every opportunity to correct their own errors.
6. Promote the personal worth of the individual user.

Figure 3. Design guidelines for interactive systems (R. W. Pew and A. M. Rollins, 1975).[9] Pew and Rollins echo Hansen's motto and add some of their own besides. Guideline No. 4, above, was probably intended to mean "adapt the messages to the user's level of syntactic and semantic knowledge."

Introduce through experience

Immediate feedback

Use the user's model

Consistency and uniformity

Avoid acausality

Query-in-depth (tutorial aids)

Sequential—parallel tradeoff
  (allow choice of entry patterns)

Observability and controllability

Figure 4. Guidelines for designing interactive systems (Brian R. Gaines and Peter V. Facey, 1975).[10] Gaines and Facey emphasize the importance of the user being in control of the terminal, the pace of the interaction, the tutorial aids, and the execution process.

Simple: project a "natural," uncomplicated "virtual" image of the system.

Responsive: respond quickly and meaningfully to user commands.

User-controlled: all actions are initiated and controlled by the user.

Flexible: flexibility in command structures and tolerance of errors.

Stable: able to detect user difficulties and assist him in returning to correct dialogue; never "dead ending" the user (i.e., offering no recourse).

Protective: protect the user from costly mistakes or accidents (e.g., overwriting a file).

Self-documenting: the commands and system responses are self-explanatory and documentation, explanations, or tutorial material are part of the environment.

Reliable: not conducive to undetected errors in man-computer communication.

User-modifiable: sophisticated users are able to personalize their environment.

Figure 5. Interface design for time-sharing systems (D. R. Cheriton, 1976).[11] Cheriton's thorough list provides good guidelines for interactive system designers.

Simplicity
  Few keywords
  Simplicity of input
  Short commands
  Simple commands
Clarity
  Hierarchical structure (commands and subcommands)
  Functional separation of commands
  Homogeneity (same structure for all commands)
  Problem orientation
Uniqueness
  Determinism—every command is fully determined by its operands and preset options
  No undefined states
Comfortable language
  Powerful commands
  Flexibility
  Short dialogue
  Data structures can be displayed and utilized for searching and browsing
Other comfort
  Input comfort: rereading or previous input or output after corrections have been made, menu technique
  Dialogue can be interrupted at any time
  Clear, short, understandable system messages
Evidence and reusability
  Evidence of the system state
  Acknowledgment of executed commands
  Help functions
  Former commands and output reusable for input
  Saving commands for later execution
Stability
  Clear messages on severe input errors
  Error correction on slight errors
  Uniform error handling
  No compulsion to continue the dialogue in a fixed way
Data security

Figure 6. Design criteria for documentation retrieval languages (F. Gebhardt and I. Stellmacher, 1978).[12]

Forgiveness—ease in repairing errors

Segmentation—layered approach

Variety—choice of style

Escape—break out of danger

Guidance—direction and learning

Leverage—flexible, powerful features

Figure 7. Human/machine interface design criteria in a computerized conferencing environment (M. W. Turoff, J. L. Whitescarver, and S. R. Hiltz, 1978).[13]

Use terse "natural" language, avoid codes, allow abbreviations.

Use short entries to facilitate error correction and maintain tempo.

Allow user choice of single or multiple entries.

Maintain "social element" to the communication.

Permit user to control length of cues or error messages.

Error messages should be polite, meaningful, and informative.

Give help when requested or when users are in difficulty.

Simple, logically consistent command language.

Control over all aspects of the system must appear to belong to the user.

Avoid redundancy in dialogue.

Adapt to the user's ability.

Keep exchange rate in user's stress-free range: user can control rate.

Figure 8. Ground rules for a "well-behaved" system (T. C. S. Kennedy, 1974).[14] **This list is based on experimental studies with data entry.**

messages such as "SYNTAX ERROR" and give helpful, informative statements such as "UNMATCHED RIGHT PARENTHESIS." Constructive messages and positive reinforcement produce faster learning and increase user acceptance.

Control

A driving force in human behavior is the desire to control. Some individuals have powerful needs to attain and maintain control of their total environment; others are less strongly motivated in this direction and are more accepting of their fate. With respect to using computers, the desire for control apparently increases with experience. Novice terminal users and children are perfectly willing to follow the computer's instructions and accept the computer as the controlling agent in the interaction. With experience and maturity, users resent the computer's dominance and prefer to use the computer as a tool. These users perceive the computer as merely an aid in accomplishing their own job or personal objectives and resent messages which suggest that the computer is in charge.

The Library of Congress recognized this distinction in changing the prompting message from the authoritarian "ENTER NEXT COMMAND" to the servile "READY FOR NEXT COMMAND." A large bank offers a banking terminal which displays the message "HOW CAN I HELP YOU?" This is appealing at first glance, but after some use, this come-on becomes annoying. The illusion that the machine is just like a human teller is perceived as a deception and the user begins to wonder about other ways in which the bank has been deceptive. The attempt to dominate the interaction, by implying that the terminal will help the user by emphasizing the "I," violates common rules of courtesy. If a starting message is used at all, it probably should focus on the customer—for example, "WHAT DO YOU NEED?" followed by a list of available operations. In any case the user should initiate the operation by hitting a button labeled "START," thus reinforcing the idea that the user is in control of the machine.

Early computer-assisted instruction systems heaped praise on the student and "wisely" guided the student through the material at a computer-selected pace; more recent systems merely display performance scores and provide an environment where the student chooses the path and pace. Only children appreciate praise from a computer; most people achieve internal satisfaction if their performance is satisfactory. Instead of the lengthy "VERY GOOD, YOU GOT THE RIGHT ANSWER," the simple display of "++" signals a correct answer to a problem.

Reinforcement for these ideas comes from Jerome Ginsburg of the Equitable Life Assurance Society, who prepared an in-house set of guidelines for developing interactive applications systems. He makes the powerful claim that

> Nothing can contribute more to satisfactory system performance than the conviction on the part of the terminal operators that they are in control of the system and not the system in control of them. Equally, nothing can be more damaging to satisfactory system operation, regardless of how well all other aspects of the implementation have been handled, than the operator's conviction that the terminal and thus the system are in control, have "a mind of their own," or are tugging against rather than observing the operator's wishes.

Being in control is one of the satisfying components of time-sharing and of programming in general. Systems which are designed to enhance user control are preferred. One explanation of why word processing systems have come into widespread use in only the last few years is that mini and microcomputers give users a powerful feeling of being in control compared to the time-shared usage of a large machine. Files kept on floppy disks are tangible when compared to disk files on an unseen remote machine. Although failures, loss of files, and faulty disks probably occur more often on the stand-alone minis and micros than on larger systems, the users of minis and micros have the satisfaction of controlling their own destiny.

Closure

One of the byproducts of the limitation on human short-term memory is that there is great relief when information no longer needs to be retained. This produces a powerful desire to complete a task, reduce our memory load, and gain relief. *Closure* is the completion of a task leading to relief. Since terminal users strive for closure in their work, interactions should be defined in sections so completion can be attained and information released. Every time a user completes editing a line or ends an editing session with an EXIT or SAVE command, there is relief associated with completion and attaining closure.

The pressure for closure means that users, especially novices, may prefer multiple small operations to a single large operation. Not only can they monitor progress and ensure that all is going well, but they can release the details of coping with early portions of the task. One informal study showed that users preferred three separate menu lists, rather than three menus on the screen at once. Although more typing and more interactions were required for the three separate menus, the users preferred doing one small thing at a time. With three menus at a time, the information about the first menu decision must be maintained until the system acknowledges or the RETURN key is hit. Similarly, word processor users may make three separate changes on adjacent words, when one large change command could have accomplished the same results with fewer keystrokes.

Response time

Most designers recognize that a simple limit on response time, the time it takes for the system to respond to a command (e.g., two seconds), is an unreasonably crude specification. Some systems have design specifications of two-second response time for 90 percent of the commands and 10-second response time for the remaining 10 percent. A more informed view is that the acceptable response time is a function of the command type. Users are not disturbed to wait several seconds for the loading of a file or large program, but expect immediate response to editing commands or emergency requests. R. B. Miller[18] provides a list of 17 command types and reasonable response times (Table 1). We may disagree with specific entries or suggest new entries, but the idea of having different response times seems acceptable. In fact, one possible approach is to guarantee that more complex and expensive commands require longer waits. This will tend to make users favor faster, cheaper commands.

A contrasting design goal is to minimize the variance of response time. It has been confirmed by experiment[19] that increasing the variability of response time generates poorer performance (Figure 9) and lower user satisfaction (Figure 10). Users may prefer a system which always responds in 4.0 seconds to one which varies from 1.0 to 6.0 seconds, even through the average in the second case is 3.5. Apparently users can devote 3.9 seconds to planning if they are sure that the time is available. If attention has to be maintained on the screen, users will not use the response time for planning work. Some users even report surprise and disruption if the response is too prompt. Holding responses to minimize response time variance may actually improve user performance and satisfaction. For extremely long response times—i.e., more than 15 seconds—the user should be informed of the time required. One graphics system shows a clock hand ticking backwards counting off the seconds until the system will respond. Even if the response is ready earlier, the system continues its countdown to zero.

Table 1.
System response times as function of user activity (R. B. Miller, 1968).[18]

USER ACTIVITY	"MAXIMUM" RESPONSE TIME (SECONDS)
CONTROL ACTIVATION (FOR EXAMPLE, KEYBOARD ENTRY)	0.1
SYSTEM ACTIVATION (SYSTEM INITIALIZATION)	3.0
REQUEST FOR GIVEN SERVICE	
SIMPLE	2.0
COMPLEX	5.0
LOADING AND RESTART	15.0-60.0
ERROR FEEDBACK (FOLLOWING COMPLETION OF INPUT)	2.0-4.0
RESPONSE TO ID	2.0
INFORMATION ON NEXT PROCEDURE	< 5.0
RESPONSE TO SIMPLE INQUIRY FROM LIST	2.0
RESPONSE TO SIMPLE *STATUS* INQUIRY	2.0
RESPONSE TO COMPLEX INQUIRY IN TABLE FORM	2.0-4.0
REQUEST FOR NEXT PAGE	0.5-1.0
RESPONSE TO "EXECUTE PROBLEM"	< 15.0
LIGHT PEN ENTRIES	1.0
DRAWINGS WITH LIGHT PENS	0.1
RESPONSE TO COMPLEX INQUIRY IN *GRAPHIC* FORM	2.0-10.0
RESPONSE TO DYNAMIC MODELING	–
RESPONSE TO GRAPHIC MANIPULATION	2.0
RESPONSE TO USER INTERVENTION IN AUTOMATIC PROCESS	4.0

Installers of time-sharing systems report user dissatisfaction in two situations where response time variance is a factor. In the first case, when a new time-sharing system is installed and the workload is light, response times are low and users are pleased. As the load increases, the response time will deteriorate to normal levels and produce dissatisfaction. By slowing down the system when it is first installed, the change is eliminated and users seem content. A second case occurs when the load on a time-sharing system varies substantially during the day. Users become aware of the fast and slow periods and try to cram their work into the fast periods. Although this approach does help to balance the load, users tend to make errors while working quickly to beat the crowd. Anxiety is increased, complaints increase, and programmers or terminal users may even be unwilling to work during the slow periods. By eliminating the variance in response time, service is perceived to be more reliable and one source of anxiety can be reduced.

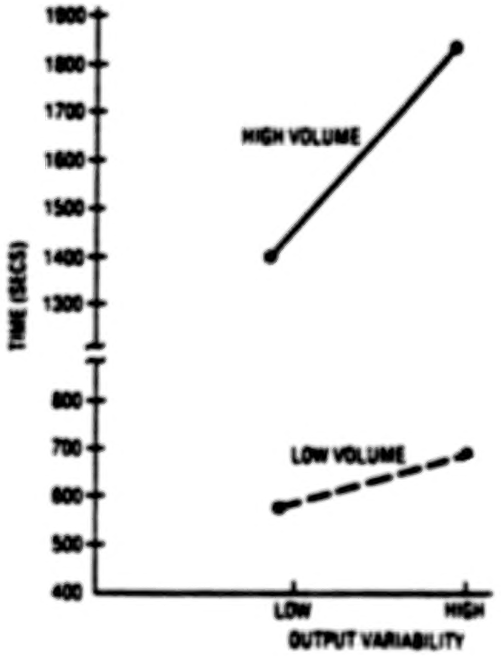


Figure 9. Graph of time to complete tasks vs. output variability for low volume and high volume. (L. H. Miller, 1977).[19]

In summary, response time is an intriguing issue whose complexities have not yet been unraveled. We are left with several conflicting design goals:

- Response time should be reduced under all conditions.
- Response time should match the complexity and cost of the command.
- Variance of response time should be reduced even at the expense of some increase in mean response time.
- System performance should not vary over time.

In an experiment studying the effect of system response time on performance in a multi-parameter optimization task, solution time increased significantly with system response time.[20] Subjects modified five parameters with light pen touches till a curve matched requirements. Each of the 30 subjects performed the task with fixed system response times of 0.16, 0.72, and 1.49 seconds. Figure 11 shows that decreasing the response time from 1.49 to 0.72 seconds reduces the solution time for this task.

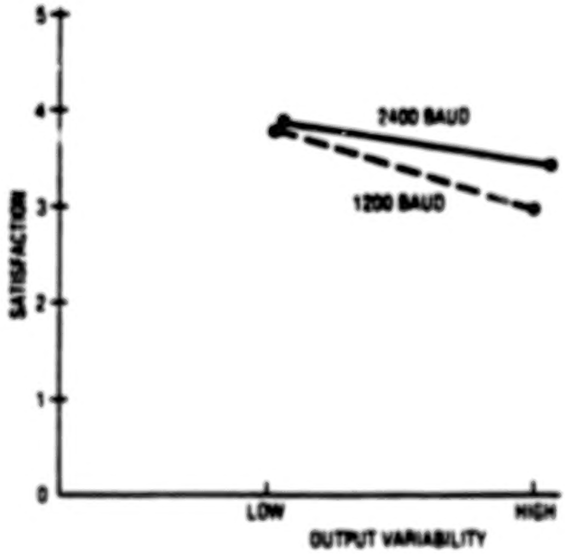


Figure 10. Graph of average response to post-test questionnaire vs. output variability for 1200 and 2400 baud (L. H. Miller, 1977).[19]

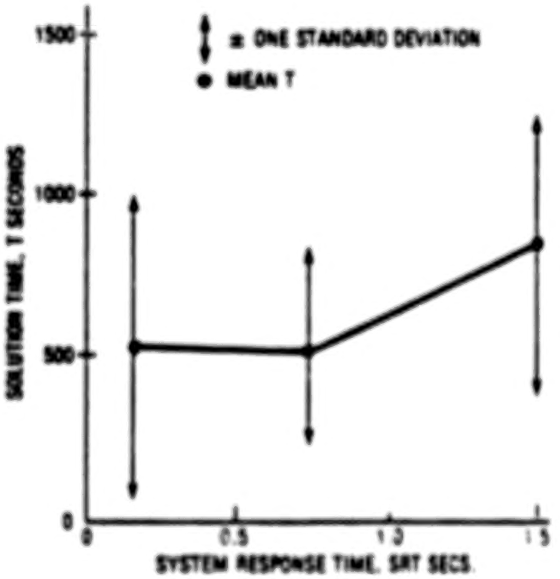


Figure 11. Solution time (T) versus System Response Time (SRT) for 30 subjects (Goodman and Spence, 1978).[20]

Grossberg, Wiesen, and Yntema[21] studied four subjects performing 36 interactive tasks involving calculations on numeric arrays. Response times were varied from 1 to 4 to 16 to 64 seconds. As the response time increased subjects became more cautious, used fewer commands, and took longer time between commands, but the total time consumed showed surprising invariance with respect to the response time increase. The subjects changed their working style as the response time increased by becoming more cautious and by making heavier use of hard copy printouts. The difference in results between this experiment and the previous one may be a product of the available commands, required tasks, or subject experience.

A related aspect of response time is the thought time of the terminal user. For complex decision-making, there is some evidence that locking the terminal for a short period, say 25 seconds in one pilot study, may improve user performance on the decision and increase user satisfaction. An open keyboard and partial attention to the display can distract the users and interfere with problem-solving while increasing anxiety. The illusion of "dialog" may compel users to keep their end of the "conversation" going. A decision-making study[22] with longer lockout times (5 and 8 minutes) revealed that subjects with no lockout used twice as much computer time and, as might be expected, the lockout groups expressed dissatisfaction with restricted access. The high variance in performance of the 20 subjects made it impossible to assess the impact of lockout, although the highest performance mean was achieved by the 5-minute lockout group. Possibly if users perceive the computer as a tool, they may be more willing to take their time and reflect on decisions. If users feel they are involved in a "dialog" in which they must respond promptly, anxiety and poorer performance may result. Maybe we should replace the term "dialog" with "utilog" conveying the impression that the user is utilizing the system as a tool.

Time-sharing vs. batch processing

As technological developments allowed programmers to use interactive terminals for preparing and executing their programs, a controversy arose over the relative merits of interactive usage and traditional batch submittal. Adherents of time-sharing argued that waiting for processing by batch-oriented computer systems was annoying, disruptive, and time-consuming. Others felt that time-sharing encouraged sloppy and hasty programming, which in turn led to more errors and poorer quality work.

Two of the earliest studies comparing on-line and off-line processing were by Schatzoff, Tsao, and Wiig[23] and Gold.[23] The former study showed a 50 percent higher total cost for time-sharing, and a 50-percent greater elapsed time for batch, with no difference in computer time. More compilations were made on-line, suggesting less time is spent in desk checking. According to Gold,[24] the "user's attitude appears to be one of the variables which may influence the user's immediate behavior and usage of computer systems." Both studies agreed that some performance variations may be attributable to programmer and problem differences.

Smith[25] examined the effects of conventional batch versus instant batch (less than 5 minutes). With respect to elapsed time (time from the start of a problem to its completion) and student reaction, instant surpassed conventional.

Summarizing five studies comparing on-line to off-line problem solving (including the two mentioned above), Sackman[26,27] stated that time-sharing had a 20-percent advantage over batch in hours used, whereas batch surpassed time-sharing with a 40-percent advantage in CPU time. In regard to cost, neither mode outperformed the other. Sackman suggested that "the comparison ... is becoming academic as the contest converges toward interactive time-sharing and fast or even instant batch." These studies need to be reevaluated and redone since hardware speeds and software capabilities have changed substantially in the last decade.

As a result of experimentation with junior college students, the use of time-sharing was recommended to alleviate the high drop-out rate from the introductory computer science courses.[28] The immediate feedback of time-sharing was seen as positively reinforcing.

The decrease in literature comparing the two modes of program development and the increase in articles on time-sharing systems give the illusion that the controversy has ended and the superiority of on-line processing is accepted. But some managers and researchers suggest that time-sharing mode encourages hasty program development and increases the number of errors. They feel that the slower turnaround of batch processing produces more careful program design and thorough desk debugging.

In a related application of interactive systems, J. V. Hansen[29] investigated performance differences for two management decision-making tasks using time-sharing and batch approaches. Both problems, stochastic capital budgeting and product demand forecasting, were not solvable by a mathematical algorithm. Instead, they required heuristic approaches where feedback from each interaction would suggest new decision rules. The results (Table 2) demonstrate that in this environment time-sharing

Table 2.
Decision-making performance averages using time-sharing and batch modes (J. V. Hansen, 1976).[29]

	GROUP A (BATCH/ON-LINE) (5 SUBJECTS)	GROUP B (ON-LINE/BATCH) (5 SUBJECTS)
PROBLEM 1 (CAPITAL BUDGETING)	82.0 (BATCH)	88.4 (ON-LINE)
PROBLEM 2 (PRODUCT DEMAND FORECAST)	90.6 (ON-LINE)	84.6 (BATCH)

access significantly improved the quality of the decisions.

In short, the experimental results suggest that a good time-sharing system is better than a bad batch system. Correcting minor errors quickly in time-sharing mode speeds productivity and reduces irritation. For more fundamental work, some programmers may abuse the rapid access of time-sharing, make hasty patches, and produce poor code.

In all the experimental results, the influence of individual differences apparently played a major role. The high variance in performance and conflicting anecdotal evidence suggests that unmeasured factors such as personality may influence preference and performance. Whether or not a programmer wants to use interactive equipment may be an important consideration. Merely because many programmers, perhaps even a majority, prefer interactive mode does not mean that all programmers should utilize that mode. Those individuals who feel more secure with a deck of keypunch cards are just as necessary to an organization.

Many variables enter into a programmer's preference for a particular computer communication alternative. In an effort to identify specific personality traits influencing preference, Lee and Shneiderman[30] studied locus of control and assertiveness.

Locus of control focuses on the perception individuals have of their influence over events. Internally controlled individuals perceive an event as contingent upon their own action, whereas externally controlled people perceive a reinforcement for an action as being more a result of luck, chance, or fate; under the control of other powerful people; or unpredictable.

Assertive behavior "allows an individual expression in a manner that fully communicates his personal desires without infringing upon the right of others."[31] Assertive individuals can state their feelings; nonassertive people have difficulty doing so.

Table 3.
Preference scores and personality factors (Lee and Shneiderman, 1978).[30]

	BATCH 0	1	2	3	TIME SHARING 4	MEAN	TOTAL OBSERVATIONS
LOCUS DIMENSION:							
INTERNAL	0	0	2	2	2	3.0	6
EXTERNAL	0	0	8	4	0	2.3	12
							18
ASSERTIVENESS DIMENSION:							
LOW	0	0	5	3	0	2.4	8
HIGH	0	0	5	3	2	2.7	10
							18

Many programmers learned use of keypunch equipment before being introduced to time-sharing. It would be less anxiety provoking for them to remain with a mode of program entry which is familiar—i.e., keypunch—than to attempt on-line communication with its many problems—e.g., signing on or possible loss of an editing session. It seems that individuals who view themselves as more effective and powerful, or internally controlled, would master on-line interaction with the computer, while those who see themselves as less powerful and not very independent or effective, or externally controlled, would continue to process by batch.

Likewise, more assertive programmers would not let the intimidating terminal inhibit them from learning and using interactive equipment. They would be able to ask for help when needed, thus promoting their learning process. The nonassertive individual might look for a means of program entry which allows least contact with others, including avoidance of equipment which could require a great deal of help and guidance during the familiarization stage. Weinberg[32] conjectures that "humble programmers perform better in batch environments and assertive ones will be more likely to shine on-line."

Subjects for our exploratory study were programmers from a Control Data Corporation installation, which allows the choice of either card or terminal entry. Three questionnaires, one to measure locus of control, one to ascertain assertiveness, and another to determine on-line or off-line preference were distributed via interoffice mail.

When the 18 responses were grouped by preference scores (Table 3), the batch group did not differ significantly from the interactive group on either personality dimension: locus of control or assertiveness. However, when the sample was grouped by internal locus/high assertive and external locus/low assertive (Table 4), there was a significant difference in mean preference scores. Confirming studies need to be carried out with more subjects in a wide variety of programming environments.

Although our findings in this exploratory study showed mixed results, the import lies in the attempt to identify variables entering into a programmer's preference for either batch or time-sharing. If programmers are allowed to use the mode they prefer, their performance and job attitude could improve. If

Table 4.
Average preference scores for personality groups (Lee and Shneiderman, 1978).[30]

	INTERNAL LOCUS/ HIGH ASSERTIVE	EXTERNAL LOCUS/ LOW ASSERTIVE
MEAN PREFERENCE SCORE	3.34	2.54
VARIANCE	0.399	0.108
NUMBER OF SUBJECTS (TOTAL NUMBER WAS 18)	4	6

preference is affected by the type of task, the availability of different modes may again improve performance. When recruiting programmers for a time-sharing environment, managers may find that those who desire to work on-line will produce better products in that environment than those who prefer working in a batch environment.

Text editor usage

A rapidly growing mode of computer use is by way of text editors, document preparation systems, and word-processing equipment. These tools allow users to construct files containing programs, alphanumeric data, correspondence, or general textual information. The diversity of user experience and the range of user patterns is enormous. Sophisticated frequent users differ from infrequent users, who are all very different from novice users. The variety of hardware and software environments further increases the choices for text editor designers and users.

Experimental comparisons of text editors are providing information about usage patterns, suggesting directions for development projects, and aiding development of a cognitive model. Walther and O'Neil[17] report on an experiment with 69 undergraduate computer science students: 41 percent had never used an on-line system, 38 percent had some experience, and 22 percent had much experience. The three experimental factors were flexibility (one version of the editor was inflexible; the second version permitted abbreviations, default values, user declaration of synonyms, a variety of delimiters, and other features), display device (cathode ray tube and impact teletype, both at 10 cps), and attitude (three subjective tests indicating attitude towards computers and anxiety). The subjects performed 18 corrections to a text file while errors were tabulated and timing data was collected. Experienced users worked faster with the flexible version, but inexperienced users were overwhelmed by the flexible version. The inexperienced users made fewer errors and worked faster with the inflexible version. The impact teletype users worked faster and made fewer errors, suggesting that the feedback from the impact may facilitate performance. Those with negative attitudes made more errors. Walther and O'Neil offer interaction effects, conjectures, potential design rules, and research directions.

Sondheimer[33] describes an experiment with more than 60 professional programmer users of a text editor. With active participation of the subjects, five features were chosen for addition to the text editor. Announcements, documentation, and training were provided, but after some initial testing, usage of the features dropped off substantially. Sondheimer concludes that "the results of the experiment seem to indicate the persistence of individual usage habits." This experiment has implications which go beyond the use of text editors, but it does emphasize that text editing is a skill which is deeply ingrained in the user's mind and difficult to change. Sondheimer conjectures that novice users of the text editor would more frequently employ the newly added features.

Card[34] and Card, Moran, and Newell[35,36] provide detailed reports on text editor experiments and offer cognitive models of human performance. Their experiments emphasize in-depth study of a limited number of highly trained subjects. Subjects performed manuscript editing tasks with a variety of line and display editors while precise timing measurements were made automatically. Text editing is characterized as a "routine cognitive skill" which "occurs in situations that are familiar and repetitive, and which people master with practice and training, but where the variability in the task, plus the induced variability arising from error, keeps the task from becoming completely routine and requires cognitive involvement."[35] A cognitive model based on goals, operators, methods, and selection rules (GOMS model) is proposed and is claimed to represent the performance of expert users. User style in locating a line (by jumping ahead a given number of lines or by locating a character string) and correcting text (by substitution or by subcommands for modifying characters in a line) was compared among subjects with the goal of predicting behavior in future situations.

Card, Moran, and Newell[35] use data from 28 subjects, on 10 systems, and over 14 task types to support the keystroke model of editor usage, suggesting that task performance time can be predicted from a unit task analysis and the number of keystrokes required. This model has strict requirements: "The user must be an expert; the task must be a routine unit task; the method must be specified in detail; and the performance must be error-free." The timing data from a variety of users and systems reveals important differences, such as the speed advantage of display editors over line editors (about twice as fast). The timing data from Card[33] demonstrates the clear speed and accuracy advantages of a mouse for selecting text, when compared with a joystick, step keys, or text keys.

Error handling

The error-checking and handling components of an on-line system may occupy the majority of the programming effort. Well-designed diagnostic facilities and error messages can make a system appealing. When user entries do not conform to expectations, diagnostic messages should guide the user in entering correct commands. Messages should be brief, without negative tones, and should be constructive. Avoid ringing bells and bold messages which may embarrass the user. Instead of meaningless messages like "ILLEGAL SYNTAX," try to indicate where the error occurred and what may be done to set it right. If possible, allow users to modify the incorrect command rather than forcing complete reentry. Command and programming languages should be designed so that a common error will not be interpreted as a valid command.

Error messages should be included in the system documentation, so that users know what to expect and so that designers cannot hide sloppy work in the system code.

The system should permit easy monitoring of error patterns so that system design can be modified in response to frequent errors. Simple tallies of error occurrences may suggest modifications of error messages, changes to command languages, or improved training procedures.

An intriguing issue in error handling is whether the error message should be issued immediately or when the end-of-line code (usually ENTER or RETURN key) is hit. A nicely designed study[37] suggests that human performance improves if errors are issued immediately and that the disruption of user thought processes by immediate interruption is not a serious impediment. Seventy undergraduate subjects in this experiment had to list 25 of the 50 states in the USA and list 20 permutations of "abcde" such that "c" occurs somewhere before the "d." The results of the permutation task strongly favor immediate interruption, but the results of the states task were mixed (Table 5). A powerful advantage of immediate interruption is that changes can be made simply by replacing the incorrect character.

A central problem in handling errors is providing the user with the right kind of information. Experienced frequent users need only an indication that an error has occurred, such as a locked keyboard, a light, or a special character. As soon as the error has been brought to their attention, they will probably recognize it and be prepared to make an immediate correction. Typical users familiar with the operations or semantics of the domain merely require a brief note to remind them of proper syntax or list of available options. Novice users whose semantic knowledge is shallow need more than prompting on syntax; they need explanations of possible commands and the required syntax. Since even experts may forget or be novices with respect to some portions of a system, a simple scheme based on recording user experience levels is unworkable. Probably the best approach is to give control to the user and provide options—maybe "?" for a brief prompt about syntax, a second "?" for a brief prompt about semantics, and a third "?" for a more detailed explanation. Users could strike "??" or "???" initially to get complete information right away.

Table 5.
Average performance results to error correction styles (Segal, 1975).[37]

	STATES TASK		PERMUTATION TASK	
	ERROR CORRECTION METHOD			
	IMMEDIATE	END	IMMEDIATE	END
PERCENT ERROR KEYPRESSES	2.55	1.99	4.54	4.48
TOTAL TIME (SECONDS)	234.0	300.0	408.8	546.4
TWO CONSECUTIVE RESPONSES IN ERROR	1.17	1.17	1.00	2.77
NUMBER OF RESPONSES IN ERROR	4.29	3.77	4.46	4.83

This question mark scheme is a simple approach to what are generally referred to as "HELP" systems. Typing "HELP" or merely "H" the user can get some information; "HELP FILES," "HELP EDIT," "HELP FORTRAN," etc., may invoke more extensive topic-oriented HELP facilities. "HELP HELP" should provide information about available facilities. The PLATO instructional system offers a special HELP key which offers appropriate guidance for the material currently on the screen.

Practitioner's summary

Do not violate the bounds of human performance imposed by limited short-term memory capacity. Design interactions in a modular fashion so that closure can be obtained providing satisfaction and relief for users. Be sensitive to user anxiety and desire for control. Provide novice users with the satisfaction of accomplishment and a sense of mastery, but avoid patronizing comments. Consider response time requirements as part of the design, not as an uncontrollable aspect of system performance.

Respect user preferences in choice of batch or interactive program development. Accept the personality and cognitive style differences among individuals and do not attempt to make everyone behave as you do.

Devote substantial energy to error design. Make messages constructive and give guidance for using the system in a courteous nonthreatening way. Prepare all messages as part of the system design and make them available in user manuals. Give users control over what kind of and how much information they wish at every point in the interaction. Do not require them to identify themselves at the start as novices. HELP facilities should be available for every command.

Respect and nurture the user community. Listen to their gripes with sympathy and be willing to modify your system to accommodate their requests. Remember, the goal is not to create a computerized system, but to serve the user. ■

Acknowledgments

This article was adapted from portions of the forthcoming book, *Software Psychology: Human Factors in Computer and Information Systems* (Winthrop Publishers). The support for computer resources was provided by the University of Maryland Computer Science Center. Helpful comments on earlier drafts of this paper were provided by Jim Foley, John Gannon, Tom Love, G. Michael Schneider, John C. Thomas, Jr., and Jerry Weinberg.

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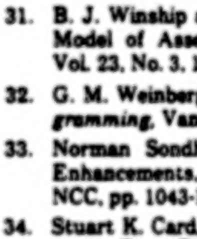

Ben Shneiderman, an associate professor at the University of Maryland, has produced five books (including the forthcoming *Software Psychology*) plus 50 articles on data-base management, programming, and human factors. After receiving his PhD in computer science from the State University of New York at Stony Brook, he spent three years teaching in the Department of Computer Science at Indiana University, before coming to the University of Maryland in 1976.

DESIGN OF INTERACTIVE SYSTEMS

DR. BEN SHNEIDERMAN
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"USER FRIENDLY"

- PROPER FUNCTIONALITY
- SYSTEM RELIABILITY
- REASONABLE COST
- HUMAN ENGINEERING CRITERIA LINKED TO BENCHMARK SET OF TASKS AND SPECIFIC USER COMMUNITY
    - TIME TO LEARN
    - SPEED OF PERFORMANCE
    - RATE OF ERRORS
    - USER SATISFACTION
    - RETENTION

DISADVANTAGES

INCREASED INITIAL COSTS

POSSIBLY LONGER DEVELOPMENT TIMES

ADVANTAGES

IMPROVED PRODUCT QUALITY

REDUCED LIFETIME COSTS

SUPERIOR RELIABILITY

SIMPLER TO TEACH/LEARN

EASIER TO REPAIR

EASIER TO MODIFY

RESEARCH METHODS

- INTROSPECTION, PROTOCOL ANALYSIS
- FIELD, CASE STUDIES
- CONTROLLED EXPERIMENTATION

CONTROLLED EXPERIMENT

- STATE HYPOTHESES
- ALTER INDEPENDENT VARIABLES
- MEASURE DEPENDENT VARIABLES
- CONTROL FOR BIASING
- USE STATISTICAL TESTS TO VERIFY HYPOTHESES

INTERACTION STYLES

MENU SELECTION
- NO TRAINING
- NO MEMORIZATION
- PROVIDES STRUCTURE FOR USER ACTIVITY
- EASY TO DESIGN USER AIDS
- SIMPLE SOFTWARE
- BIG DEVELOPMENT EFFORT
- CAN BE RESTRICTIVE

FILL-IN-THE-BLANK
- MODEST TRAINING
- EASY TO DESIGN USER AIDS
- APPROPRIATE FOR DATA ENTRY AND RETRIEVAL
- MODERATE DEVELOPMENT EFFORT
- CAN BE RESTRICTIVE

PARAMETRIC, COMMAND OR QUERY LANGUAGE
- SUBSTANTIAL TRAINING
- POWERFUL
- FLEXIBLE
- DIFFICULT TO PROVIDE USER AIDS

MENU SELECTION GUIDELINES

- USE 4-8 CHOICES PER SCREEN UNLESS THERE IS GOOD REASON TO CHANGE (PHILLIPS ET AL., TELIDON, 1980) (MILLER, HFS, 1981)
- CONSIDER SEMANTIC ORGANIZATION AND GIVE TITLE
- SHOW HIERARCHY BY GRAPHIC DESIGN/TYPOGRAPHY
- PERMIT SIMPLE BACK, LEFT, RIGHT TRAVERSALS
- PERMIT TYPE-AHEAD
- PUT MOST IMPORTANT/FREQUENT CHOICES FIRST
- BEGIN CHOICES WITH KEYWORD, IF POSSIBLE
- USE BLANK LINES TO SEPARATE GROUPS OF CHOICES
- REQUIRE ENTER KEY OR USE AUTOMATIC MODE CONSISTENTLY

OTHER CONSIDERATIONS

DISPLAY RATE

RESPONSE TIME

HELP/EXPLAIN FACILITIES

SHORT CUTS/MENU MACROS

TEXT EDITOR USAGE

COMPARISON OF SYMBOL EDITOR	KEYWORD EDITOR
FIND:/TOOTH/;-1	BACKWARD TO "TOOTH"
LIST; 10	LIST 10 LINES
RS:/KO/,/OK/;*	CHANGE ALL "KO" TO "OK"

	PERCENTAGE OF TASK COMPLETED		PERCENTAGE OF ERRONEOUS COMMANDS	
	SYMBOL	KEYWORD	SYMBOL	KEYWORD
INEXPERIENCED USERS (8)	28	42	19	11
FAMILIAR USERS (8)	43	63	18	6.4
EXPERIENCED USERS (8)	74	84	9.9	5.5

(LEDGARD, WHITESIDE, SINGER & SEYMOUR, CACM 1980)

COMMAND + MENU SELECTION FORMATS

- 106 PROFESSIONALS AT NASA/JPL COMPLETED EXPERIMENT
- VARIETY OF TASKS IN SHIP CONTROL ENVIRONMENT:
  PROPULSION, NAVIGATION, RADAR, WEAPONS

45 SHORT FORM MNEMONIC (ONE COMMAND/PARAMETER)	COMPLETION RATE	TIME ON FIRST ATTEMPT	TIME ON SECOND ATTEMPT	LIKED=1 DISLIKED=7
+ FUNCTIONALLY GROUPED MANUAL	81%	785	624	3.69
+ ALPHABETIC MANUAL	70%	925	620	4.57
8 LONG FORM MNEMONIC + MANUAL (MANY PARAMETERS GROUPED BY FUNCTION)	88%	542	449	3.46
46 PROMPTS FOR PARAMETERS + MANUAL	81%	457	400	3.48
46 MENU OF CHOICES	85%	447	401	2.96

(CHAFIN & MARTIN, NASA/JPL 955013/RD-142, 11/80)

DISPLAY RATE IMPACT

- SCROLLED CRT LESSONS ON PAPERMAKING
- LOW ABILITY SUBJECTS
- LATIN SQUARE DESIGN FOR PRESENTATION ORDERING
- FOUR REPEATED MEASURES FOR EACH OF 12 SUBJECTS

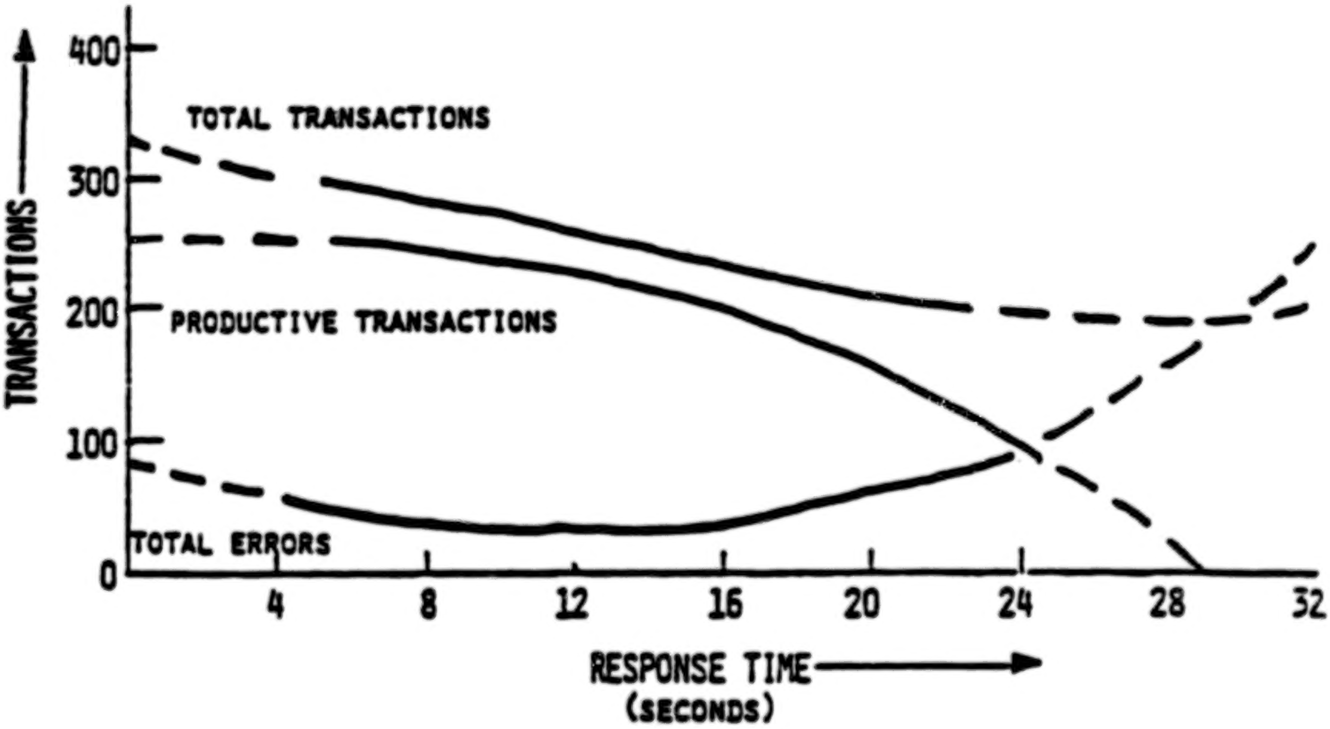
CPS	CAI ERRORS	SUBJECTIVE PREFERENCE (0=BEST, 3=WORST)	LESSON TIME	USER RESPONSE TIME
10	3.0	.7	22 MIN	5.7 SEC
15	3.1	1.1	17 MIN	8.0 SEC
15 BY WORDS	3.3	1.6	18 MIN	8.2 SEC
60	4.3	2.5	12 MIN	22.5 SEC

(BEVAN, *IJMMS*, 1981)

RESPONSE TIME

- 19 UTILITY COMPANY CLERKS IN EXPERIMENTAL GROUP IN 8 WEEK STUDY AGAINST CONTROL GROUP
- COMPLEX ORDERING PROCEDURE
- JOB SATISFACTION QUESTIONNAIRES SHOWED DISSATISFACTION WITH LONGER RESPONSE TIME

(DASHED LINES INDICATE PROJECTION)



(BARBER & LUCAS, 1982)

RESPONSE TIME DESIGN GUIDELINES

INDIVIDUAL CHARACTERS SHOULD APPEAR WITH NO DELAY

SYSTEM SHOULD RESPOND TO SIMPLE COMMANDS WITHIN A SECOND

- GOODMAN AND SPENCE, SIGGRAPH (1978)
- S. WEINBERG, CDC (1981)
- DOHERTY, IBM (1979)

LONGER THAN 15 SECOND DELAYS MAY DISRUPT THINKING

- R. MILLER (1968)
- BARBER & LUCAS (1982)

CONSISTENT RESPONSE TIME WITHIN A SESSION, A DAY, AND OVER LONGER TIMES MAY INCREASE USER SATISFACTION

LOCKING THE KEYBOARD TO REQUIRE USER THINKING MAY INCREASE TASK PERFORMANCE AND USER SATISFACTION

- BOEHM, SEVEN & WATSON, SJCC (1971)

ADVISE USERS OF LONG RESPONSE TIMES

USER BEHAVIOR IS SHAPED BY RESPONSE TIMES

- GROSSBERG, WIESEN & YNTEMA, IEEE-SMC (1976)

SYSTEM RESPONSE TIMES AS FUNCTION OF USER ACTIVITY

USER ACTIVITY	"MAXIMUM" RESPONSE TIME
CONTROL ACTIVATION (FOR EXAMPLE, KEYBOARD ENTRY)	0.1 SECOND
SYSTEM ACTIVATION (SYSTEM INITIALIZATION)	3.0
REQUEST FOR GIVEN SERVICE:	
SIMPLE	2
COMPLEX	5
LOADING AND RESTART	15-60
ERROR FEEDBACK (FOLLOWING COMPLETION OF INPUT)	2-4
RESPONSE TO ID	2
INFORMATION ON NEXT PROCEDURE	< 5
RESPONSE TO SIMPLE INQUIRY FROM LIST	2
RESPONSE TO SIMPLE STATUS INQUIRY	2
RESPONSE TO COMPLEX INQUIRY IN TABLE FORM	2-4
REQUEST FOR NEXT PAGE	0.5-1
RESPONSE TO "EXECUTE PROBLEM"	< 15
LIGHT PEN ENTRIES	1.0
DRAWINGS WITH LIGHT PENS	0.1
RESPONSE TO COMPLEX INQUIRE IN GRAPHIC FORM	2-10
RESPONSE TO DYNAMIC MODELING	-
RESPONSE TO GRAPHIC MANIPULATION	2
RESPONSE TO USER INTERVENTION IN AUTOMATIC PROCESS	4

(MILLER, 1968)

ERROR MESSAGE SAMPLES

```
FATAL ERROR, RUN ABORTED
DISASTROUS STRING OVERFLOW, JOB ABANDONED
CATASTROPHIC ERROR, LOGGED WITH OPERATOR

SYNTAX ERROR
ILLEGAL COMMAND
INVALID DATA

TRANS ERR-CTL OPEN
FAC REJCT 004000040000
OC7, OC4
GUARD MODE ERROR 2
IEH2191
```

SYSTEM MESSAGES

SHOULD NOT	SHOULD
BE	BE
-WORDY	-BRIEF
-NEGATIVE IN TONE	-POSITIVE
-CRITICAL OF ERRORS	-CONSTRUCTIVE
-GENERAL	-SPECIFIC
-CRYPTIC	-COMPREHENSIBLE
SUGGEST SYSTEM CONTROL OVER THE USER	EMPHASIZE USER CONTROL OVER SYSTEM

OTHER CONSIDERATIONS

- UPPER AND LOWER CASE IS PREFERRED TO UPPER CASE ONLY EXCEPT IN EXTREME SITUATIONS
- ASTERISKS SHOULD BE USED ONLY IN EXTREME SITUATIONS
- ERROR NUMBERS, IF NEEDED AT ALL, SHOULD BE AT THE END OF THE MESSAGE
- USER MODIFIABLE MESSAGE FILE
- TWO OR MORE LEVELS OF MESSAGES

SYSTEM MESSAGES EXAMPLES

POOR	BETTER
ENTER NEXT REQUEST	READY FOR NEXT COMMAND
ILLEGAL COMMAND	LOAD OR SAVE:
SYNTAX ERROR	UNMATCHED LEFT PARENTHESIS
INVALID ENTRY	DRESS SIZES RANGE FROM 5 TO 16
FAC RJCT 000400040000	FILE MUST BE OPENED BEFORE READING
THE PROCESSING OF THE TEXT EDITOR YIELDED 23 PAGES OF OUTPUT ON THE LINE PRINTER.	OUTPUT 23 PAGES

JOB CONTROL ERRORS

- IBM MVS JCL ERRORS CAPTURED OVER FIVE WEEKS AT BOEING COMPUTER SERVICES

- 513 OUT OF 2073 ERRORS WERE RETRIES

THE 9 MOST COMMON JCL ERRORS

Msg ID	#	%	Message Text
IEF605	920	29%	UNIDENTIFIED OPERATION FIELD
IEF607	578	18%	JOB HAS NO STEPS
IEF621	226	7%	EXPECTED CONTINUATION NOT RECEIVED
IEF630	224	7%	UNIDENTIFIED KEYWORD
IEF612	182	6%	PROCEDURE NOT FOUND
IEF632	182	6%	FORMAT ERROR
IEF657	162	5%	SYMBOL NOT DEFINED IN PROCEDURE
IEF623	112	4%	SOURCE TEXT CONTAINS UNDEFINED OR ILLEGAL CHARACTERS
IEF624	97	3%	INCORRECT USE OF PERIOD

ON-LINE ASSISTANCE

- KEEP IN MIND THE DISTINCTION BETWEEN
  HELP WITH SYNTAX PROBLEMS
  EXPLANATIONS OF SPECIFIC FEATURE SEMANTICS
  TUTORIALS FOR SYSTEM USAGE
- ALLOW USER CONTROL OVER DEGREE OF DETAIL
- USE CONSISTENT/PREDICTABLE SCREEN FORMATS
  SO USERS WILL REMEMBER WHERE TO FIND INFORMATION
- ON-LINE ASSISTANCE CAN BE MORE CONFUSING AND DISRUPTIVE TO
  TRUE NOVICES THAN SIMPLE PAPER MANUALS (RELLES, 1979)

(12 SUBJECTS PER GROUP)	MEAN SCORES ON INFORMATION RETRIEVAL TASK (MAX = 30)
WELL-WRITTEN EXPLANATION ON-LINE	7.0
WELL-WRITTEN EXPLANATION ON PAPER (2 PAGES) PLUS CRYPTIC ON-LINE INTRODUCTION	13.5
CRYPTIC ON-LINE INTRODUCTION ONLY	12.0

(DUNSMORE, ACM CONF., 1980)

TRAINING MANUALS FOR TEXT EDITING

- STANDARD MANUAL VS. MODIFIED MANUAL
  ALL DETAILS ABOUT A COMMAND vs. SPIRAL APPROACH
  ABSTRACT DESCRIPTIVE NOTATION vs. NUMEROUS EXAMPLES
  TERSE DESCRIPTIONS vs. READABLE EXPLANATIONS

- ADVANCE ORGANIZER, 15-30 MINUTES OF STUDY, NINE COMPLEX EDITING OR CREATION TASKS, THREE HOUR MAXIMUM

	STANDARD MANUAL	MODIFIED MANUAL
TASKS COMPLETED	7.36	8.77
AVERAGE MIN/TASK	26.63	16.00
AVERAGE EXIT ERRORS/TASK	1.36	.27
AVERAGE COMMANDS/TASK	23.63	13.04
AVERAGE REQUESTS FOR VERBAL HELP	5.50	2.55

(FOSS, ROSSON & SMITH.
HUMAN FACTORS IN COMPUTER SYSTEMS, 1982)

GRAPHICS INPUT

- OPTICAL CHARACTER RECOGNITION
- TV IMAGE PROCESSING
- PATTERN RECOGNITION IMPROVES
- LIMITED SEMANTIC INTERPRETATION

GRAPHICS OUTPUT

- GRAPHS, HISTOGRAMS, ETC.
- LINE DRAWINGS - HIDDEN LINE REMOVAL
- ROTATION
- SHADING
- FULL COLOR PICTURES

GRAPHICS INTERACTION

- COMPUTER AIDED DESIGN
  - CIRCUIT LAYOUT
  - AUTOMOBILE DESIGN
  - ARCHITECTURE
  - MAPPING
  - NUMERICAL CONTROL MACHINE TOOLS
- EXCELLENT WHEN MODIFICATIONS ARE REQUIRED

AUTOMATIC SPEECH RECOGNITION/GENERATION

ISOLATED WORD RECOGNITION

- 98% ACCURACY
- LIMITED VOCABULARY (LESS THAN 50 WORDS)
- SPEAKER DEPENDENT "TRAINING"
- COMMERCIALLY VIABLE WHEN
    1) WORKER'S HANDS BUSY
    2) MOBILITY REQUIRED
    3) WORKER'S EYES BUSY
    4) HARSH ENVIRONMENTS

CONTINUOUS SPEECH RECOGNITION

- RESEARCH SYSTEMS
    IBM, CMU
- NOT COMMERCIALLY VIABLE

VOICE OUTPUT

- COMMERCIALLY VIABLE
- HARDWARE EMBEDDED
- FOR SPECIAL APPLICATIONS

USER EXPERIENCE LEVELS

NOVICES NEED

- UTMOST IN CLARITY AND SIMPLICITY
- SMALL NUMBER OF COMMANDS
- MEANINGFUL COMMANDS (NOT SINGLE LETTER, NOT COMPLEX SYNTAX)
- LUCID ERROR MESSAGES AND HELP FACILITIES
- REINFORCEMENT FROM SUCCESS

KNOWLEDGEABLE INFREQUENT USERS PREFER

- SIMPLE COMMANDS
- MEANINGFUL COMMANDS
- EASY TO REMEMBER OPERATIONS
- PROMPTING

FREQUENT USERS WANT

- POWERFUL COMMANDS, COMMAND STRINGS, USER DEFINED COMMANDS
- MINIMIZE KEYSTROKES
- BRIEF MESSAGES (WITH ACCESS TO DETAIL AT REQUEST)
- HIGH SPEED INTERACTION

HOW TO SATISFY ALL USER LEVELS?

- GRACEFUL EVOLUTION
- LAYERED|SPIRAL|LEVEL STRUCTURED DESIGN
- HIDE DETAILS

PSYCHOLOGICAL ISSUES

- SHORT TERM MEMORY LOAD - SEVEN PLUS/MINUS TWO
  - KEEP DISPLAYS SIMPLE
  - MINIMIZE MEMORIZATION
  - AVOID MULTISCREEN COMPLEXITY BY USING HIERARCHICAL DESIGN

- CLOSURE - DESIRE TO COMPLETE
  - ORGANIZE SESSION INTO SECTIONS
  - EMPHASIZE TRANSITION POINTS
  - CHOOSE SEQUENCING TO AVOID LOOSE ENDS

- ANXIETY - "COMPUTER SHOCK" - FEAR OF MACHINES
  - STRIVE FOR SIMPLICITY FOR NOVICES
  - OFFER POSITIVE REINFORCEMENT FOR SUCCESS
  - TAKE GREAT CARE IN WRITING SYSTEM MESSAGES

- LOCUS OF CONTROL - DESIRE TO BE IN CHARGE
  - NOVICES MAY WISH COMPUTER DIRECTED MODE
  - EXPERTS DEMAND USER CONTROL
  - PEOPLE WANT COMPETENCE OF MASTERY

DIRECT MANIPULATION

1) PHYSICALLY DIRECT MANIPULATION OF OBJECT OF INTEREST

2) IMMEDIATE OBSERVATION OF AFFECT OF ACTION

3) INCREMENTAL REVERSIBLE ACTIONS

4) DEPENDS ON REPRESENTATION OF A COGNITIVE MODEL -
    INTUITIVELY OBVIOUS
    ANALOGICAL REASONING
    TAPS USER'S KNOWLEDGE

5) NO COMMAND LANGUAGE SYNTAX TO MEMORIZE
    SIMPLIFIES TRAINING

6) NO ERROR MESSAGES
    USER PROVIDES SELF REGULATING FEEDBACK

DISPLAY EDITORS	VS	LINE EDITORS
CONTINUOUS FULL PAGE DISPLAY		ONE LINE AT A TIME
VISIBLE CURSOR		LINE POINTER CONCEPT
PHYSICAL CURSOR ACTION		IMPLICIT LINE POINTER CHANGES
INSERT/DELETE BY KEYSTROKE		INSERT/DELETE BY COMMAND
CHANGE IN PLACE		CHANGE BY SUBSTITUTION COMMAND
PARAGRAPH/PAGE FORMAT OBVIOUS		FORMAT VISIBILITY IS POOR

CURSOR MOTION CHOICES

1) U, D, L, R — COMMANDS

2) ↑ ↓ → ← — ADJACENT ARROW KEYS

3) ← ↑ ↓ → — DIRECTIONAL ARROW KEYS

4) JOYSTICK

5) TOUCH PANEL

COMPUTER ARCADE GAMES

EQUIPMENT

- LEVERS OR ROTATING PADDLES FOR ONE DIMENSIONAL MOVEMENT
- JOYSTICKS OR TRACKBALLS FOR TWO DIMENSIONAL MOVEMENT
- BUTTONS FOR ACTIONS
- IMMEDIATE RESPONSE TO ACTION ON THE DISPLAY
- SOUND EFFECTS AND GRAPHICS

CONCEPTS

- HAND-EYE COORDINATION
- EXTREME SKILL RANGE
    - FUN FOR NOVICES
    - CHALLENGE FOR EXPERTS
- COMPETITION AGAINST MACHINE/HUMAN
- STRESS/ANXIETY
- REWARDS
    - ADDITIONAL PLAYS
    - INITIALS OF HIGH SCORERS DISPLAYED

FURTHER EXAMPLES

- FORMS FILL-IN
- QUERY-BY-EXAMPLE (ZLOOF, NCC, 1975)
- FORAL LP (SENKO, 1978)
- SPATIAL DATA MANAGEMENT (WILSON & HEROT, VLDB6, 1980)
- VISICALC
- CAR DRIVING
- PILOT CONTROLS/HORIZON INDICATOR
- SOME GRAPHICS APPLICATIONS
    - CAD/CAM
    - AUTO DESIGN
    - ARCHITECTURE

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HUMAN-COMPUTER DIALOGUE: INTERACTION TASKS AND TECHNIQUES - A SURVEY AND CATEGORIZATION

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HUMAN-COMPUTER DIALOGUE: INTERACTION TASKS AND TECHNIQUES - A SURVEY AND CATEGORIZATION

1. Introduction

Interaction techniques and devices are important parts of the user-computer interface. There are a multitude of interaction techniques: each has a specific purpose, such as to specify a command, designate a position, or select a displayed object, and each is implemented with some device, such as a tablet, joystick, keyboard, light pen, track ball, or potentiometer. Typical techniques which many readers may be familiar with are: selecting a command from a menu using a light pen, specifying a position using a tablet or joystick along with cursor feedback on the screen, typing a numeric value on a keyboard, or designating a displayed object with a light pen.

Selecting appropriate techniques and devices is an important aspect of interface design. We all recognize, from our own experiences with interactive computing (which need not have been with interactive graphics), the costs of poorly-designed interfaces. Coming in many forms, the costs can include degraded user productivity, user frustration, increased training costs, the need to redesign and re-implement the user interface, etc. Specific experiments confirm that the costs are real. How can we avoid these costs? Where can we turn for guidance? There are three basic sources of information:

1) Experience-based guidelines
2) Experiments with interaction techniques, and
3) The human-factors literature, especially that dealing with equipment design.

This paper is drawn from a lengthier report (FOLE81) of work done with V. Wallace and sponsored by the U.S. Army Research Institute (Contract MDA-903-79-G-01) and the Department of Energy, Applied Mathematics and Statistics program (Grant DE-AS05-ER10521). In the full report we elaborate on these sources of information.

The scope of our work does not extend to the physical design of interaction devices. Issues such as key shape, keyboard slant, and light pen diameter are beyond our scope and are being treated extensively in the literature of traditional human factors. Our basic guideline is that device characteristics which are normally under computer control are considered in our work, while characteristics normally built into the device hardware are not. We take the necessary liberty of assuming that whatever devices may be selected are optimally-designed for their intended use.

Most commands to an interactive system consist of several interaction tasks. A typical "move entity" command has three such tasks: a position, an entity, and the actual command, "move". Each task can be implemented by many different techniques. The designers of the interactive system must select those interaction techniques which best match both the user's characteristics and the specific requirements of the interaction task and must also select the appropriate device. In some cases the devices will already be pre-determined, having been selected by the hardware procurers rather than by the user interface designers. This unfortunate situation reduces the number of alternative design decisions to be considered and may result in a sub-optimum design.

As we will later describe in detail, each task has certain requirements which are dictated by the application and/or user, and each technique has certain properties. For example, a requirement of a positioning task may be that positions be indicated in 3D, while a property of a positioning technique may be that it works only in 2D. The 2D techniques would, therefore, not be considered for use.

We have suggested that interaction sequences can be decomposed into a series of basic interaction tasks. These tasks appear to be of only six distinct types, each of which we will describe in turn. Each interaction task has a set of requirements. For instance, a positioning task may require dynamic, continuous feedback using a screen cursor. A property of interaction techniques for positioning is the type of feedback they can provide. In the case at hand, only interaction techniques providing dynamic feedback would be considered candidates for implementing the positioning task.

Interaction techniques not only have requirements but also have hardware prerequisites which must be provided; otherwise, the technique cannot be considered. A positioning technique which provides dynamic, continuous feedback and allows movement in arbitrary directions must be supported by a continuous-motion input device such as a tablet, light pen, or touch-sensitive panel. Furthermore, the display device itself must be able to update a cursor position twenty to thirty times per second. In design situations where interaction devices have already been selected, these prerequisites serve to limit the set of interaction techniques which can be considered. When device selection is part of the design process, the prerequisites serve to link a technique being considered with required hardware characteristics.

In this paper we discuss the six basic interaction tasks, enumerate the requirements which each task may have, show how the requirements relate to the properties of interaction techniques, and, in turn, show how a technique's hardware prerequisites affect device selection. The reader is referred to FOLE82 for an account of available devices and their characteristics.

2. Interaction Tasks: Types and Requirements

An examination of interactive graphics leads us to conclude that there are six fundamental types of interaction tasks. The tasks, which are application and hardware independent, form the building blocks from which more complex interaction tasks and, in turn, complete interaction dialogues, are assembled. The tasks are user-oriented in that they are the primitive action units performed by a user. They relate to, but differ from, the logical input devices found in device-independent graphics packages (GSPC79, CARU77) and discussed previously by the authors of this report (FOLE74, WALL76) and in NEWM68 because the logical input devices are hardware and software oriented, rather than user oriented.

The six interaction tasks are:

1) Select
2) Position

3) Orient
4) Path
5) Quantify
6) Text

These are similar to the tasks described in RAMS79 and in OHLS78. The set of tasks is based not on fundamental research into users' underlying cognitive processes, but rather is based on experience with dozens of interactive graphics systems and a subsequent categorization of observed interaction acitivities into these six categories. Refinement and restudy of the tasks is a key step for future research.

2.1 Select

The user makes a selection from a set of alternatives. The set might be a group of commands, in which case typical interaction techniques are:

1) Menu selection using a light pen,
2) Menu selection using a cursor controlled by a tablet,
3) Type-in of command name, abbreviation, or number on an alphanumeric keyboard,
4) Programmed function keyboard, and
5) Voice input of the selection name.

Rather than being commands, the set of alternatives might be a collection of displayed entities which form part of the application information presentation. In a command and control application, the entities might be symbols representing troop and equipment positions.

Interaction techniques which might be used in this case are similar to those for command selection:

1) Selection by pointing, using a light pen,
2) Selection using a cursor controlled by a tablet,
3) Type-in of the entity name,
4) Selection by pointing, using a touch-sensitive panel, and
5) Voice input of the entity name.

Figure 1.1 shows the set of selection techniques which are discussed in the next chapter. As with all six interaction tasks, we do not discuss every conceivable technique, as their number is limited only by one's imagination. Rather, we limit the discussion to those techniques which have been proven in use.

The application requirements for a selection task are:

1) Size of the set from which the selection is made, if size is fixed, and
2) Range of set size, if variable.

Rather different techniques might be best for selection from a fixed set of two choices (such as "YES" and "NO") and for selection from a very large, variable sized set of displayed entities.

2.2 Position

In carrying out the positionining task the user indicates a position on the interactive display. This is typically done as part of a command to place an entity at a particular position. Customary interaction techniques for positioning are:

1) Use of a cursor controlled by a tablet, mouse, or joystick
2) Type-in of the numeric coordinates of the position, and
3) Light pen and tracking cross.

Figure 1.2 shows the positioning techniques we discuss.

The application requirements of the positioning task are:

1) Dimensionality: 1D, 2D, or 3D. Positioning in 1D simply means that the position specified is constrained to be along some line.
2) Open-loop or closed-loop. In the former case, the user knows in advance the exact coordinates of the position, so visual feedback of the position on the display is not an essential part of the process of specifying the position. In the latter case, visual feedback is important because the user adjusts the position, based on the feedback, until the desired end result has been achieved. (This is the distinction between the "discrete positional" and

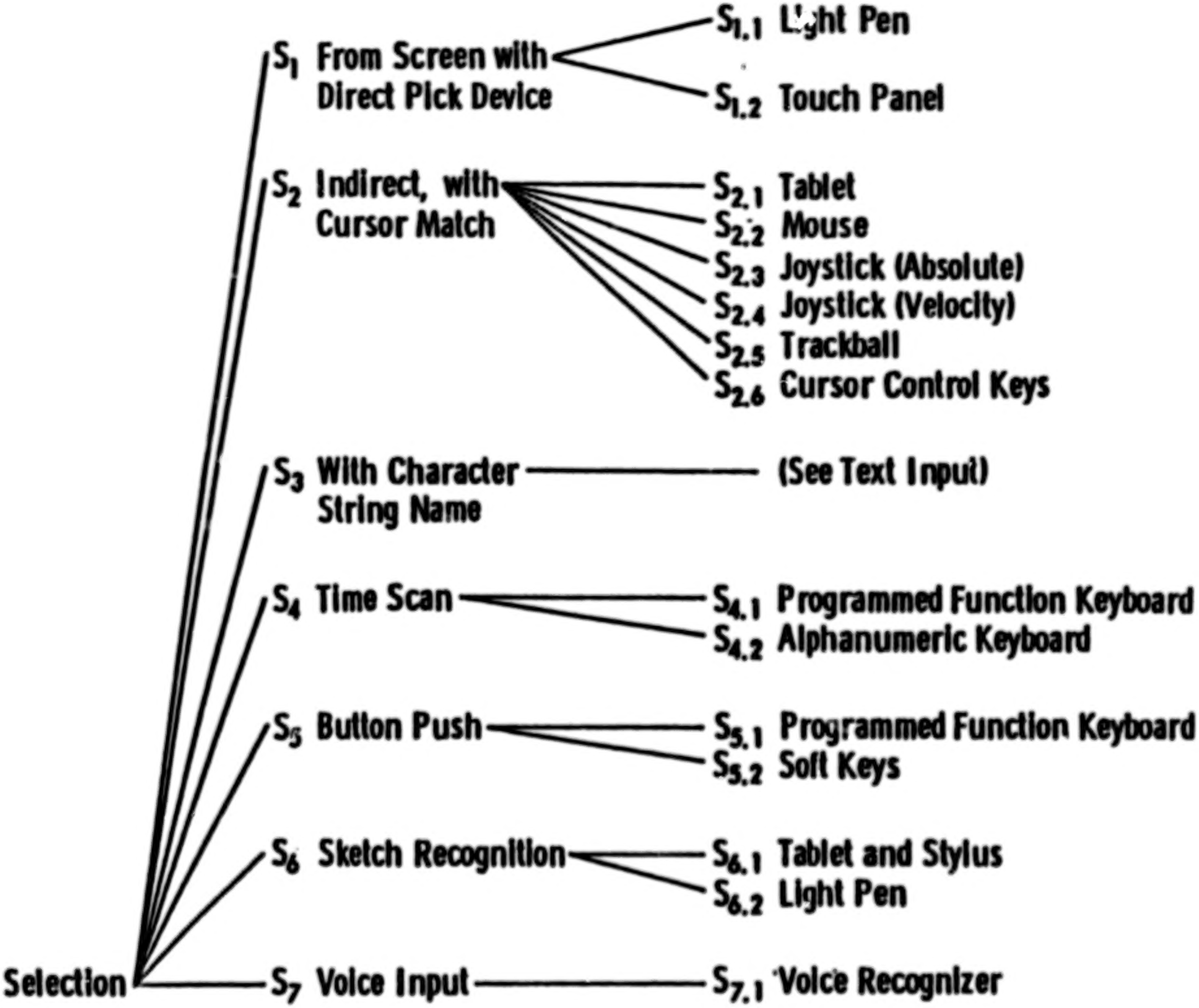
Selection
S_1 From Screen with Direct Pick Device
$S_{1.1}$ Light Pen
$S_{1.2}$ Touch Panel
S_2 Indirect, with Cursor Match
$S_{2.1}$ Tablet
$S_{2.2}$ Mouse
$S_{2.3}$ Joystick (Absolute)
$S_{2.4}$ Joystick (Velocity)
$S_{2.5}$ Trackball
$S_{2.6}$ Cursor Control Keys
S_3 With Character String Name
(See Text Input)
S_4 Time Scan
$S_{4.1}$ Programmed Function Keyboard
$S_{4.2}$ Alphanumeric Keyboard
S_5 Button Push
$S_{5.1}$ Programmed Function Keyboard
$S_{5.2}$ Soft Keys
S_6 Sketch Recognition
$S_{6.1}$ Tablet and Stylus
$S_{6.2}$ Light Pen
S_7 Voice Input
$S_{7.1}$ Voice Recognizer

Figure 1.1. Selection techniques.

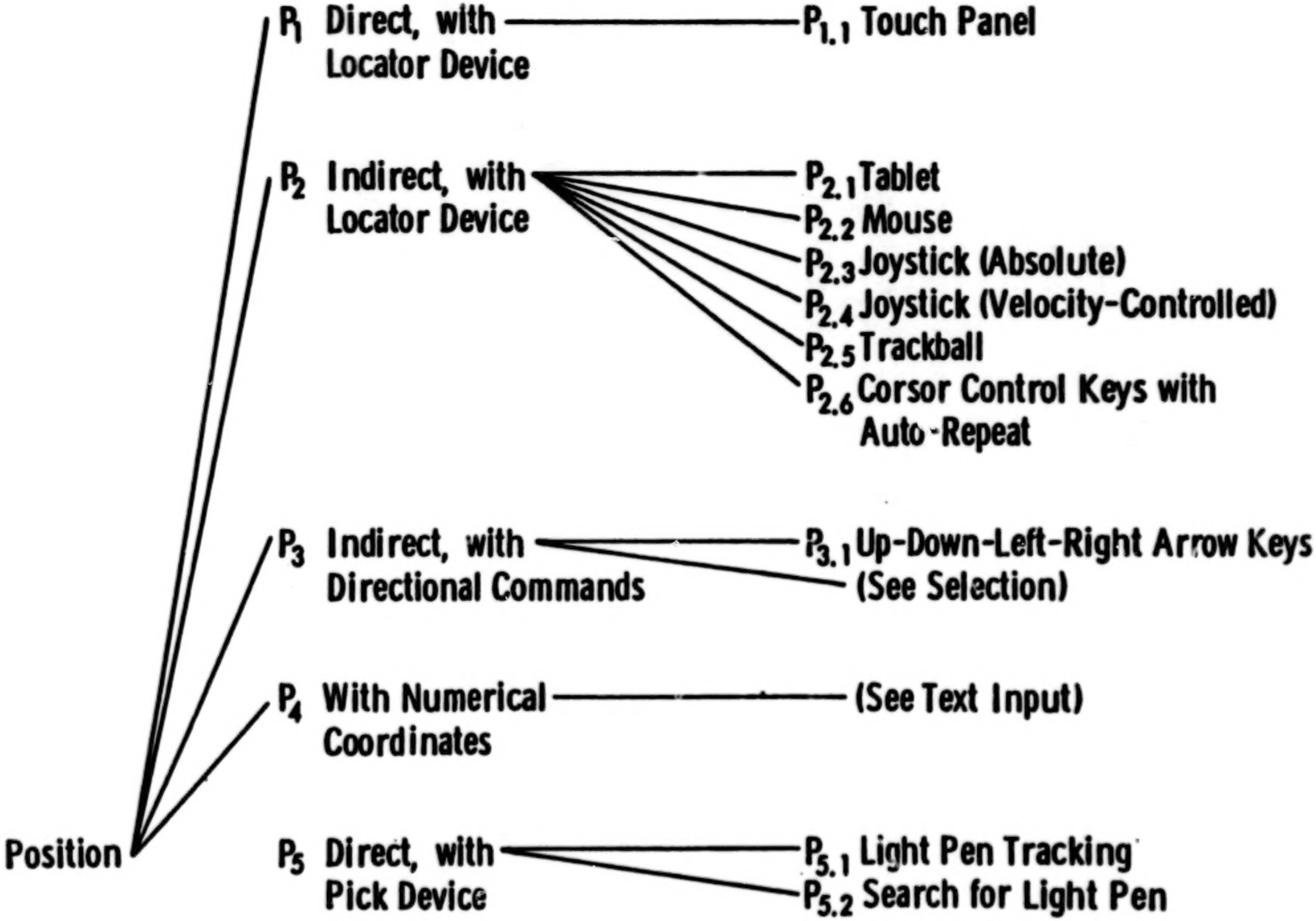
Position
P1 Direct, with Locator Device
P1.1 Touch Panel
P2 Indirect, with Locator Device
P2.1 Tablet
P2.2 Mouse
P2.3 Joystick (Absolute)
P2.4 Joystick (Velocity-Controlled)
P2.5 Trackball
P2.6 Corsor Control Keys with Auto-Repeat
P3 Indirect, with Directional Commands
P3.1 Up-Down-Left-Right Arrow Keys
(See Selection)
P4 With Numerical Coordinates
(See Text Input)
P5 Direct, with Pick Device
P5.1 Light Pen Tracking
P5.2 Search for Light Pen

Figure 1.2. Positioning techniques.

"continuous positional" tasks proposed in (RAMS79).)

3) Resolution expressed as parts of accuracy over the maximum range of coordinate value. An accuracy of .01 "over a range of 10" is one part in 1000.

2.3 Orient

The user orients an entity in 2D or 3D space. For 2D, this might mean rotating a symbol to be heading north-northeast. In 3D, it could mean controlling the pitch, roll, and yaw of the view of a terrain model.

Interaction techniques useful for the orientation task include:

1) Control of orientation angle(s) (one angle for 2D, up to three angles for 3D) using dial(s) or joystick, and

2) Type-in of angle(s) using alphanumeric keyboard.

Figure 1.3 shows the different interaction techniques used to implement an orient task.

The requirements of the orientation task are analogous to those for the positioning task. Dimensionality is replaced by the more general term "degrees of freedom", values of which can be one, two, or three. Of course it is only in a 3D space where two and three degrees of freedom make sense: in 2D, only a single degree of rotational freedom is available. On the other hand, one degree of freedom in 3D makes perfectly good sense: it is a rotation about an arbitrary axis.

2.4 Path

The user generates a path, which is a series of positions or orientations, created over time. A path is considered a fundamental interaction task, even though it consists of other primitive tasks (position or orient) because another fundamental dimension — time — is involved and because we believe this changes the user's perception of the task. With a single position or orientation, the user's atttention is focused on attaining a single end result. In the present case, by contrast, it is the series of positions or

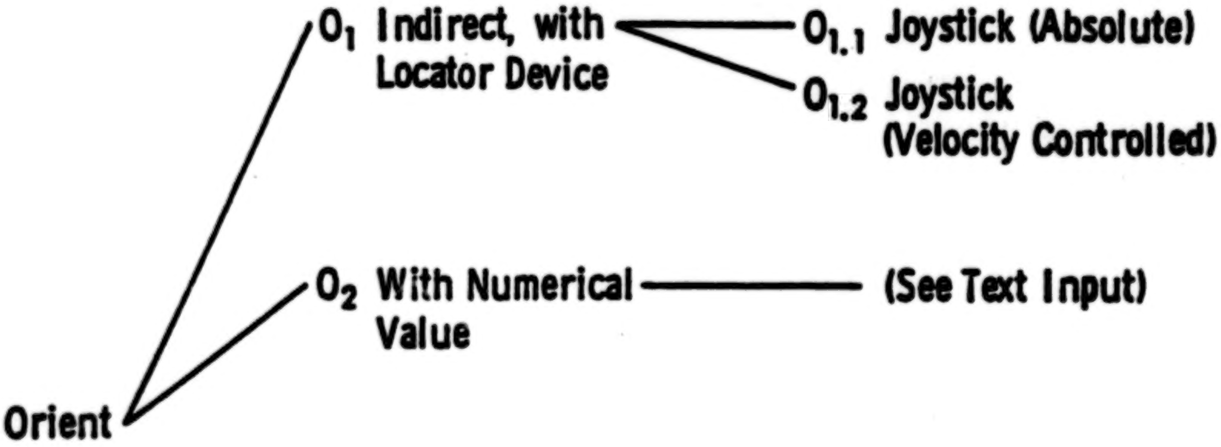
O_1 Indirect, with Locator Device
$O_{1.1}$ Joystick (Absolute)
$O_{1.2}$ Joystick (Velocity Controlled)
O_2 With Numerical Value
(See Text Input)
Orient

Figure 1.3. Orienting techniques.

orientations, and their order, which is the focus of attention.

A path of positions might be generated by a user in the process of digitizing a sketch, of indicating the routing of a run on a printed circuit board, or of showing a desired route on a map. A path of orientations and of positions would be generated in a simulated flight over a terrain model.

The techniques for generating a path are usually those position and orient task techniques which allow closed-loop feedback and typically involve use of a tablet, mouse, joystick, and/or dials. In some cases open-loop techniques might be suitable.

The requirements of a path task are:

1) Maximum number of positions or orientations along the path, if they are to be saved. For instance, positions would be saved when digitizing a shape, but might not be saved in a flight simulation.
2) The interval between each element on the path and its basis. Some paths are time-based, with a new element entered at each periodic time interval (typically 33 msec. for a real-time simulation). Other paths are distance-based, with the next element entered each time it differs from the preceding element by a predefined amount.
3) Dimensionality: 2D or 3D.
4) Open-loop or closed-loop.
5) Resolution.
6) Type: position, orientation, or both.

2.5 Quantify

The user specifies a value (i.e, number) to quantify a measure, such as the height of an entity or the value, in ohms, of a resistor. Typical techniques are:

1) Value type-in on a keyboard, and
2) Rotary or slide potentionmeter.

Figure 1.4 shows the set of quantifying techniques we shall discuss. The requirements of

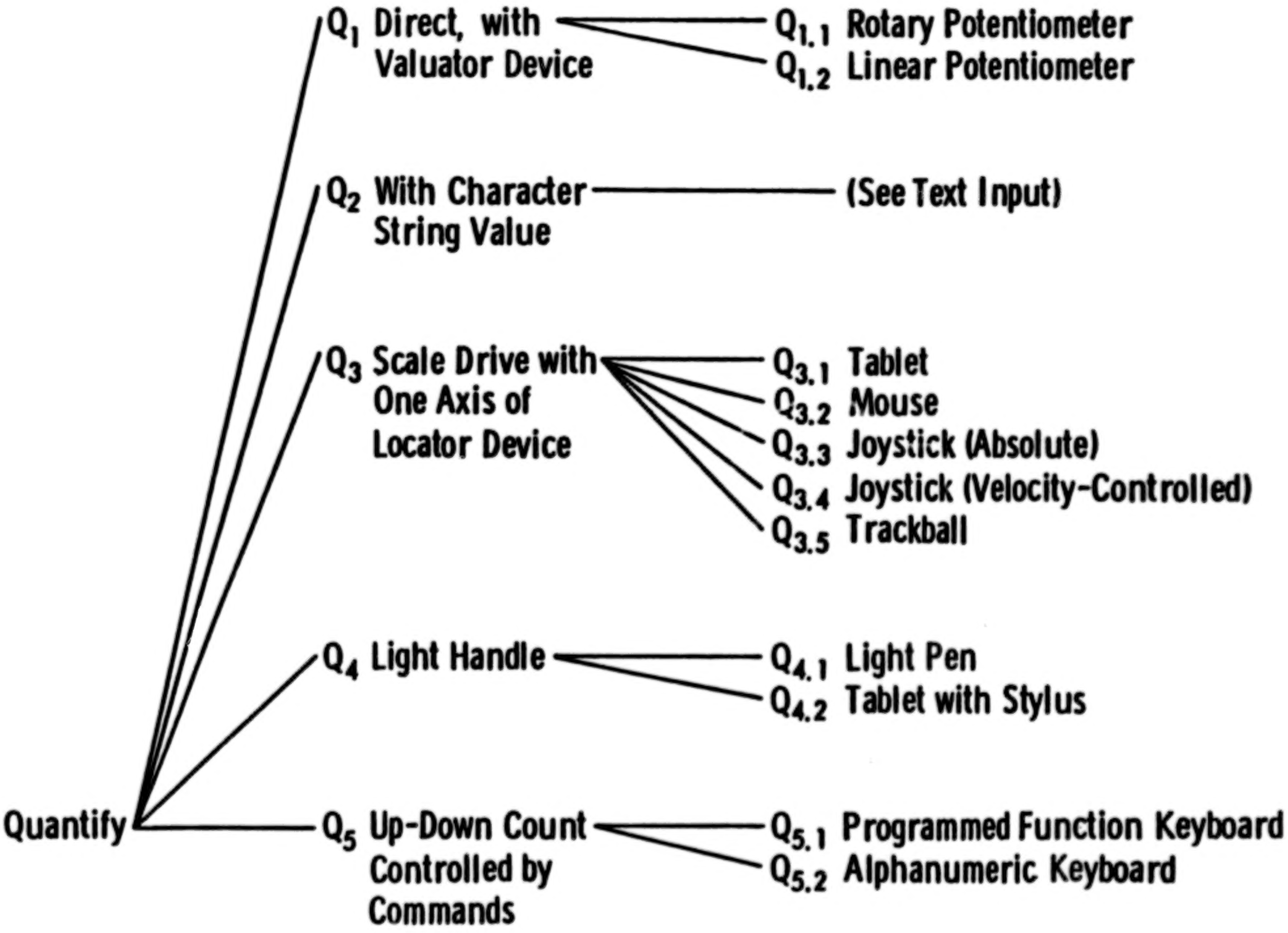
Quantify
Q_1 Direct, with Valuator Device
$Q_{1.1}$ Rotary Potentiometer
$Q_{1.2}$ Linear Potentiometer
Q_2 With Character String Value
(See Text Input)
Q_3 Scale Drive with One Axis of Locator Device
$Q_{3.1}$ Tablet
$Q_{3.2}$ Mouse
$Q_{3.3}$ Joystick (Absolute)
$Q_{3.4}$ Joystick (Velocity-Controlled)
$Q_{3.5}$ Trackball
Q_4 Light Handle
$Q_{4.1}$ Light Pen
$Q_{4.2}$ Tablet with Stylus
Q_5 Up-Down Count Controlled by Commands
$Q_{5.1}$ Programmed Function Keyboard
$Q_{5.2}$ Alphanumeric Keyboard

Figure 1.4. Quantifying techniques.

a quantification task are:

1) Resolution, expressed as number of resolvable units to be specified. For instance, age in years would require about 120 units of resolution, while angle in degrees requires 360 units.

2) Open-loop or closed-loop.

2.6 Text

The user inputs a text string, used, for example, as an annotation on a drawing or as part of a page of text. The key factor is that the text string itself becomes part of the information stored in the computer, rather than being used as a command or being converted to a value, position, or orientation. In the first case, the text input is a new interaction task, while in the latter cases, the text input is being used as an intermediary for one of the other interaction tasks. Typical interaction techniques for text input are:

1) Type-in from an alphanumeric keyboard, and

2) Character selection from a menu.

Figure 1.5 shows the text-entry techniques.

The text task has two requirements. They are:

1) Size of character set,

2) Maximum length of string to be entered.

There are other issues surrounding the text input task, such as the specific character set (as opposed to its size). Such issues, however, do not affect the choice of technique or device. The details of the character set would affect only the labels on key caps, for instance.

2.7 Summary

We have proposed that user interactions can be grouped into six task categories.Each task is implemented in practice by an interaction technique. While there are many interaction techniques to consider for each task, the task requirements limit the choice of techniques to those whose properties match the task requirements. The set

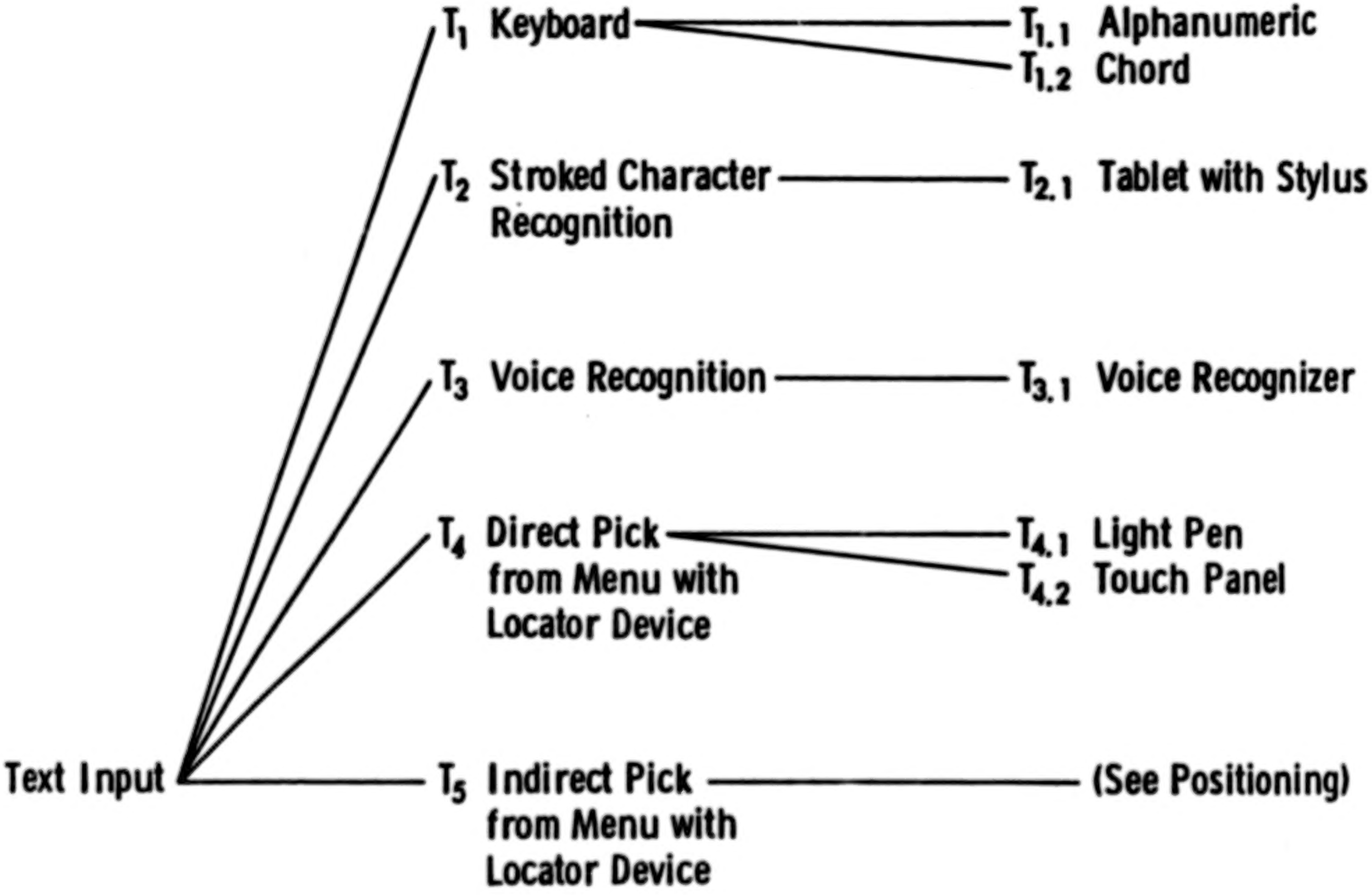
Text Input
T_1 Keyboard
$T_{1.1}$ Alphanumeric
$T_{1.2}$ Chord
T_2 Stroked Character Recognition
$T_{2.1}$ Tablet with Stylus
T_3 Voice Recognition
$T_{3.1}$ Voice Recognizer
T_4 Direct Pick from Menu with Locator Device
$T_{4.1}$ Light Pen
$T_{4.2}$ Touch Panel
T_5 Indirect Pick from Menu with Locator Device
(See Positioning)

Figure 1.5. Text-entry techniques.

of requirements for each task is derived from an analysis of the needs of the application being implemented. Table 1.1 summarizes the requirements for each task.

Table 1.1

Summary of Interactive Task Requirements

Interaction Task	Requirements
Select	Size of set, if fixed Range of set size, if variable
Position	Dimensionality: 1D, 2D, or 3D Resolution
Orient	Degrees of freedom: 1,2, or 3 Open-loop or closed-loop Resolution
Path	Maximum number of path elements to be retained Type of interval between each element on path Size of interval between each element on path Dimensionality: 2D or 3D Open loop or closed loop Resolution Type: position or orientation or both
Quantify	Resolution Open-loop or closed-loop
Text	Size of character set Maximum length of string

3. Organization of Interaction Techniques

Having in the previous section discussed interaction tasks, we now turn our attention toward the interaction techniques used to implement the interaction tasks. Figures 1.1 through 1.5 show how we have organized the techniques. The lists of techniques are by no means exhaustive, but we believe the organization will easily cover other techniques as well.

3.1 Techniques and their Variations

At the first level in these tree-like diagrams we have the fundamentally different techniques, such as menus and command type-in for the selection task in Figure 1.1. At the second level are variations on a basic technique, such as the specific physical device used to drive the cursor for selection from a menu (see Figure 1.1).

In some cases, where the technique draws on other techniques normally associated with other interaction tasks, the diagrams simply refer to another diagram.

3.2 Technique Parameters

There is another aspect to interaction techniques which is not shown in these diagrams but which does affect the characteristics of individual techniques. This is the aspect of technique parameters, specific examples of which are:

1) The form of the cursor used in connection with some of the positioning and selection techniques,
2) The ratio of hand movement to cursor movement when a tablet, joystick, mouse, or other physical positioning device is used, and
3) The layout of a menu as either a row, column, or grid of choices.

One might include hardware device characteristics, such as the length or diameter of a joystick, as technique parameters. However, following our basic tenet of taking hardware as a fixed given, we do not do so. Instead, we limit technique parameters to those aspects of a technique which are normally controllable by software.

In FOLE81, where specific techniques are discussed, we describe some technique parameters. As with basic techniques themselves, the types of parameters associated with one or more techniques are limited only by our imagination and creativity. Accordingly, we cannot be exhaustive but rather attempt to address the most substantial parameters, especially those for which human factors literature offers guidance.

Each of the techniques, as opposed to technique variations, has a set of hardware prerequisites, with respect both to the display technology as well as to the types of devices used with the technique. These prerequisites are described with each technique. A typical prerequisite, say for a closed-loop positioning technique, would be for a continuous movement physical device as well as for a display on which the feedback to the user can be dynamically repositioned 15 to 30 times per second.

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PRELIMINARY REPORT OF GODDARD/UNIVERSITY HUMAN FACTORS RESEARCH GROUP

MR. WALTER TRUSZKOWSKI
CHAIRMAN, HUMAN FACTORS
RESEARCH GROUP
GODDARD SPACE FLIGHT CENTER

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PRELIMINARY REPORT - HUMAN FACTORS RESEARCH GROUP[1]

I. INTRODUCTION

The purpose of this presentation is to introduce to you the Human Factors Research Group. A few introductory remarks are in order.

At the beginning of this symposium we were given positive indication that our immediate upper management has an interest and committment to support human factors activities in both the academic and user communities. Thus, at this point we have:

- some appreciation of what is meant by human factors, and
- an indication of management support for Goddard activities in the field

This establishes the context for my remarks. I would like to address Goddard's emerging involvement in human factors activities. In doing so I will indicate:

- the major concerns which motivated an active interest in human factors activities,
- the mechanism, the Human Factors Research Group, we are using to persue our activities,
- current activities, and
- plans for the future

Each of these points will be briefly addressed in what follows.

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[1] This is an expanded version of the presentation given at the symposium.

II. MAJOR CONCERNS

This section contains my personal views about what motivated Goddard's increasing participation in human factors activities. As I see it, there are three major concerns which helped to spark and greatly influence our initial efforts and priorities in the human factors arena. These are an increased awareness of the :

- over-riding data-driven aspects of current command/control systems,
- complexity of existing man/system interface mechanisms, and
- great extent of the manual intervention required in present systems.

Each of these concerns is briefly explained in what follows.

II.1 DATA-DRIVEN ASPECTS OF CURRENT SYSTEMS

Prime targets of applied human factors activities are those systems which support our mission and data operations activities. An analysis of these systems quickly leads to the conclusion that these systems and especially the activities they support are data/information intensive. This is defined to mean that

- the systems are highly data-driven,
- operator-initiated sequences are usually dictated by the operator's interpretation of computer-generated or manually-generated data,
- control is accomplished via data,
- monitoring is accomplished via data, and
- system output-products are data

Figure 1, which represents an extrapolation of some ideas generated by Jens Rasmussen (1), graphically illustrated the fact that all major identifiable interfaces can be considered to be directly related to data interpretation and generation.

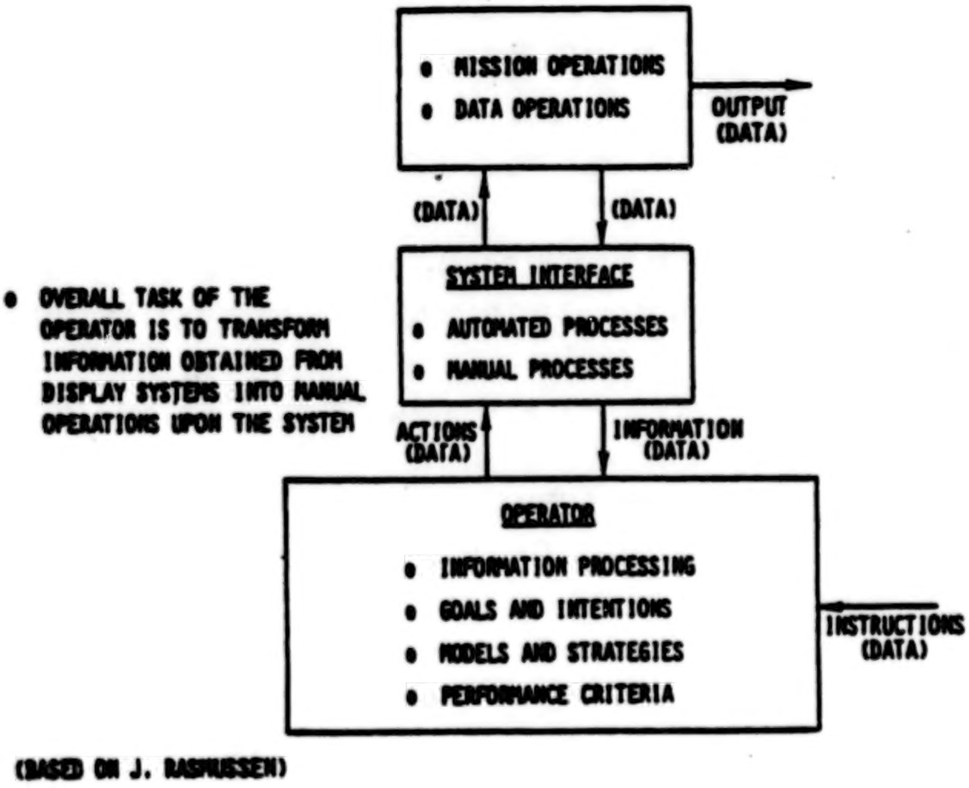

• MISSION OPERATIONS
• DATA OPERATIONS
OUTPUT (DATA)
(DATA)
(DATA)
SYSTEM INTERFACE
• AUTOMATED PROCESSES
• MANUAL PROCESSES
• OVERALL TASK OF THE OPERATOR IS TO TRANSFORM INFORMATION OBTAINED FROM DISPLAY SYSTEMS INTO MANUAL OPERATIONS UPON THE SYSTEM
ACTIONS (DATA)
INFORMATION (DATA)
OPERATOR
• INFORMATION PROCESSING
• GOALS AND INTENTIONS
• MODELS AND STRATEGIES
• PERFORMANCE CRITERIA
INSTRUCTIONS (DATA)
(BASED ON J. RASMUSSEN)

Figure 1

In view of this I feel that for a human factors program to be meaningful in Goddard's context it must address questions like the following:

- what is the "proper" relationship between the function which an operator needs to perform and the supporting data presented to him by the system

- how does or should this relationship change as a function of the expertise of the operator,
- can a formal cognitive model be established which would support qualitative and quantitative research in this area of applied human factors analysis,

•
•
•

The essence of these concerns lies in considering both the man and the system to be sources of information structures which dynamically need to be reconsiled in order to support meaningful and productive work. Figure 2 illustrates this idea.

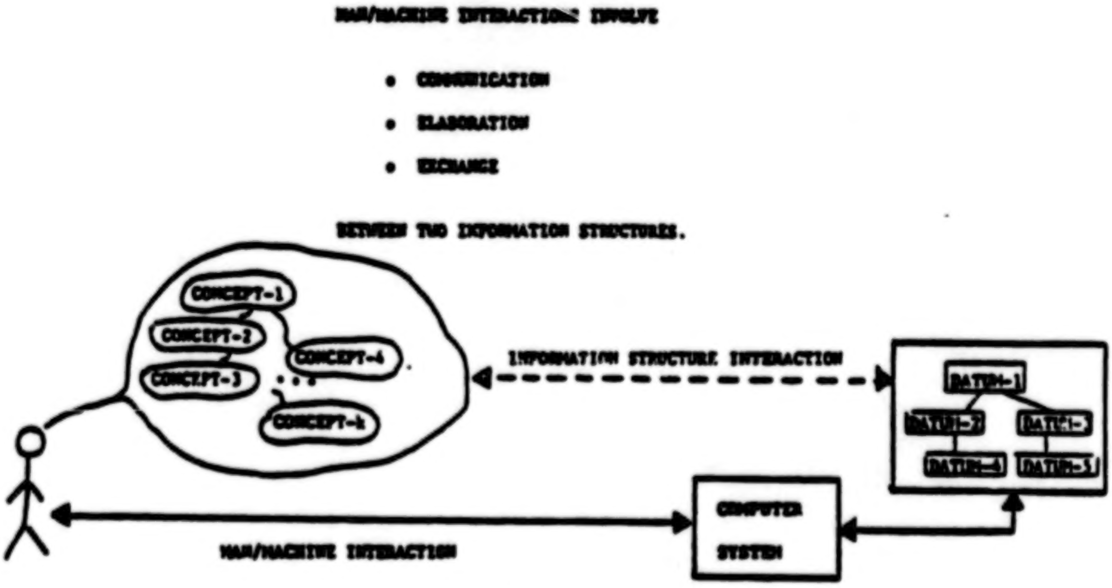
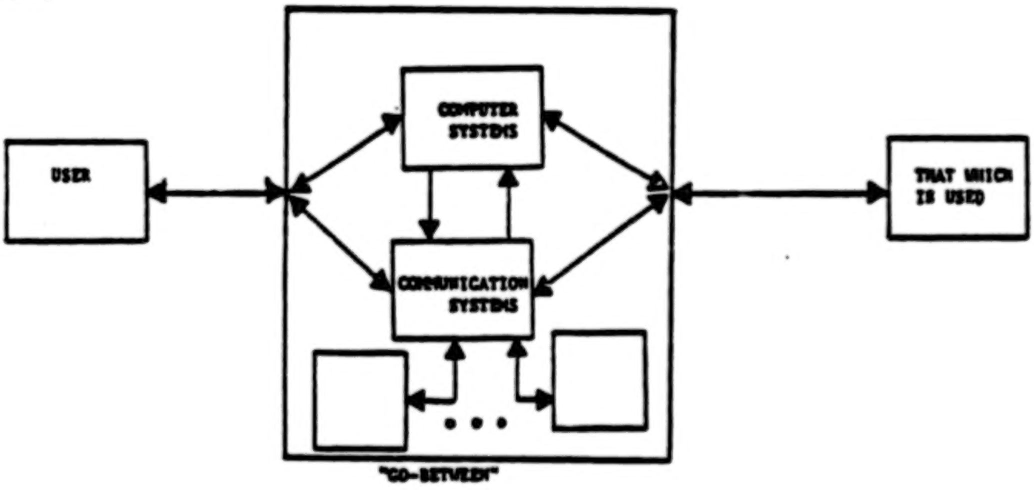

MAN/MACHINE INTERACTIONS INVOLVE
• COMMUNICATION
• ELABORATION
• EXCHANGE
BETWEEN TWO INFORMATION STRUCTURES.
CONCEPT-1
CONCEPT-2
CONCEPT-3
CONCEPT-4
CONCEPT-k
INFORMATION STRUCTURE INTERACTION
DATUM-1
DATUM-2
DATUM-3
DATUM-4
DATUM-5
COMPUTER SYSTEM
MAN/MACHINE INTERACTION

Figure 2

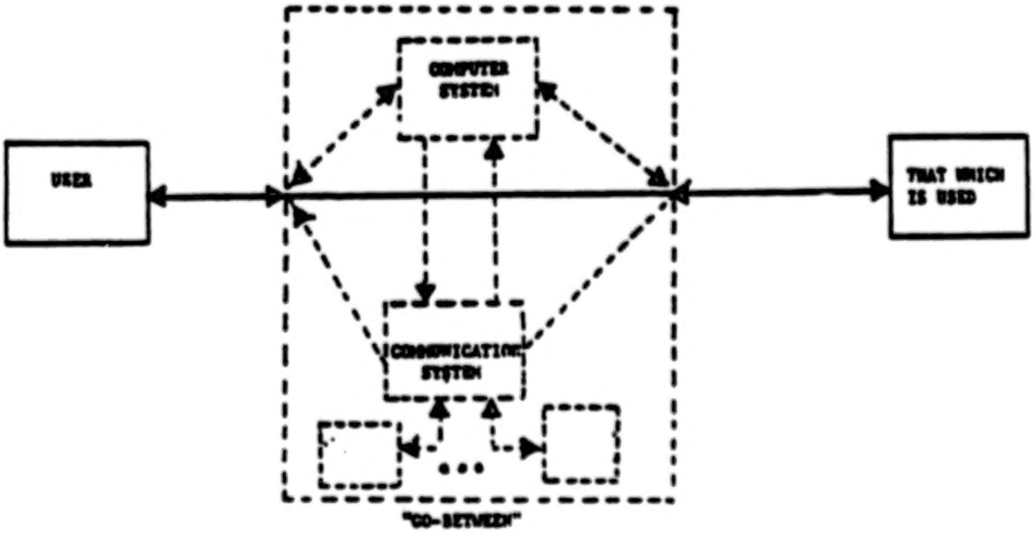
LL.2 COMPLEXITY OF MAN/MACHINE INTERFACES

It is my opinion that the real (or apparent) complexity of a system, with respect to the user, is due in large measure to the fact that the user is consciously forced to interact with the system at too low a level of interaction. Consider for a moment two complex systems - the telephone system and a typical operating system and what you have to do to get each to properly respond to your directives. It is my opinion that the complexity of the telephone system is better concealed from the user than that of the operating system. Figures 3 and 4 illustrate the ideas outlined.


USER
COMPUTER SYSTEMS
COMMUNICATION SYSTEMS
THAT WHICH IS USED
"GO-BETWEEN"

• USER IS CONSCIOUSLY AWARE OF THE "GO-BETWEEN" IN CURRENT SYSTEMS

Figure 3


USER
COMPUTER SYSTEM
COMMUNICATION SYSTEM
THAT WHICH IS USED
"GO-BETWEEN"

• "GO-BETWEEN" IS ESSENTIALLY TRANSPARENT TO USER OF THE SYSTEM

Figure 4

With regard to this concern about complexity I feel that human factors research into the nature of system complexity and how best to minimize the user's awareness of system complexity is appropriate for the Goddard environment

II. 3 EXTENT OF MANUAL INTERVENTION

This concern needs very little clarification. It is felt that in a good number of instances the poor performance of a system and the number of system errors is due primarily to the human component of the system.

To adequately address this conern from a human factors point-of-view I feel that two major activities need to be undertaken. First, we need to more fully understand the proper palcement of Goddard's systems, from a man/machine operation point-of-view, in the spectrum whose endpoints are depicted in Figure 5.

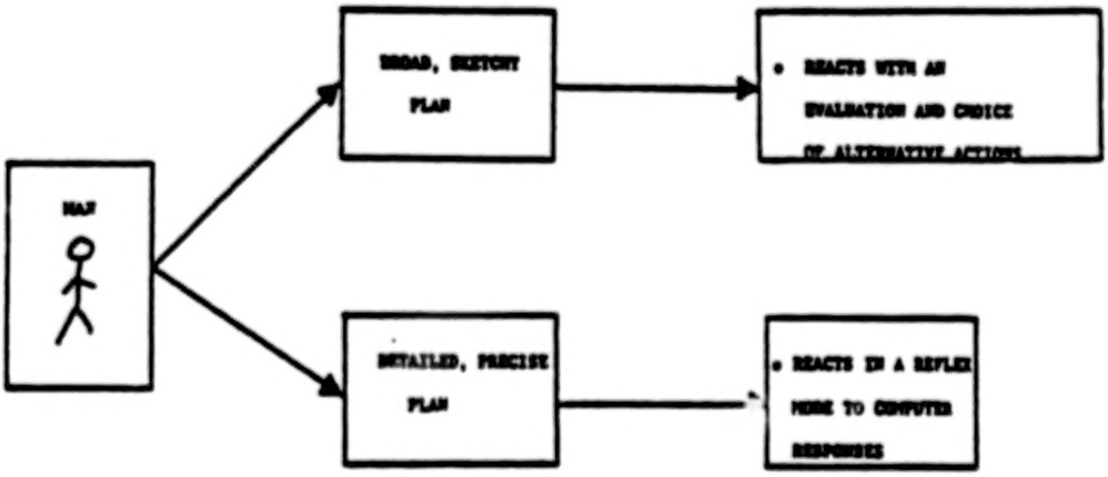

MAN
BROAD, SKETCHY PLAN
• REACTS WITH AN EVALUATION AND CHOICE OF ALTERNATIVE ACTIONS
DETAILED, PRECISE PLAN
• REACTS IN A REFLEX MODE TO COMPUTER RESPONSES

Figure 5.

Secondly, we need to provide for an adaptive mechanism approach for the placement of our man/machine interfaces. Figure 6 addresses this point. The closer the interface to the man, the higher it is and therefore requires the less manual intervention. The question which this figure raises is - is there a point of symbiosis between man and machine where the optimal manual interface is obtained. Our human factors research should address such questions.

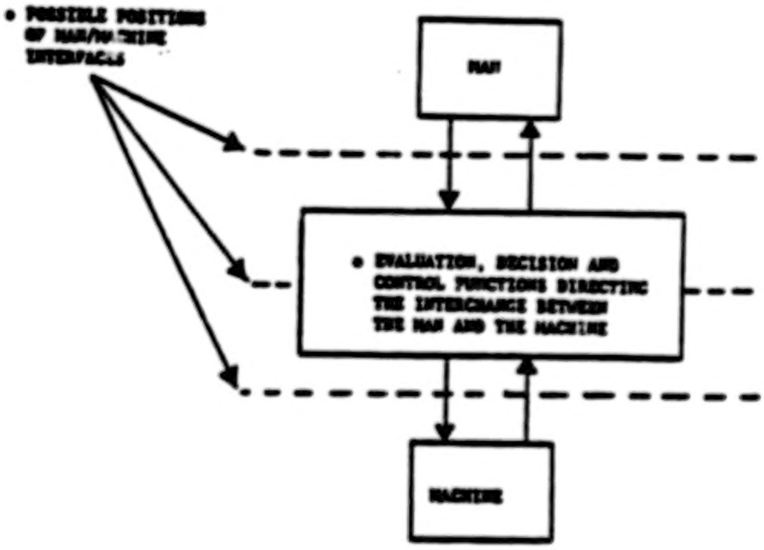

• POSSIBLE POSITIONS
OF MAN/MACHINE
INTERFACES
MAN
• EVALUATION, DECISION AND
CONTROL FUNCTIONS DIRECTING
THE INTERCHANGE BETWEEN
THE MAN AND THE MACHINE
MACHINE

Figure 6

We have addressed some of the motivations for commencing serious work in human factors. Now we turn to a brief description of the group responsible for the work.

III. THE HUMAN FACTORS RESEARCH GROUP

Once the need for a focused program addressing human factors considerations with respect to Goddard's systems was clearly identified, work began on identifying a proper vehicle for commencing activity in this area. The result was the Human Factors Research Group (HFRG). Currently, the membership of this group, formed in the late fall of 1981, comes from the Goddard Space Flight Center, The University of Maryland, George Mason University, George Washington University, and the Computer Sciences Corporation. The goals and objectives which have been established for this group are as follows:

- maintain on-going cognizance and analysis of GSFC-systems from a human factors point-of-view
- be responsible for planning, coordinating and executing generic human factors research
- provide technology transfer and/or technology infusion to specific GSFC applications or operational environments
    - be responsible for the generation, maintenance, and distribution of human factors guidelines
    - maintain awareness of state-of-the-art human factors R D activities which have or may have pertinence to the GSFC environment
        - establish/maintain a human factors resource center (printed publications, videotapes/films, sources of expertise; automated source list)
        - serve as a public relations committee, ensuring that human factors issues are brought to the attention of the GSFC community

- serve as a focal point for people at the GSFC (Government, Contractor, University, etc.) interested in human factors issues
- serve as a source of experience and expertise about human factors issues; review, critique, and document system requirements and designs from a human factors point-of-view and on an as-required basis

In order to realize its objectives the group, which meets monthly at the Goddard Space Flight Center, has adopted a fairly straight forward method of operation. the basic elements of this method are:

- gain an in-depth understanding of the Goddard environment and associated humand factors needs thru such mechanisms as
  - documenting personal experiences
  - peer presentations
  - relevant documentation
  - interviews
  - on-side observations
  - demonstrations

    •
    •
    •
- define meaningful work by
  - identifying and/or being presented with specific problems requireing applied human factors analysis
  - identifying the generic problem which is a generalization of the more specific problem

  - defining, executing and documenting the appropriate research

- realize a technology infursion or transfer by

  - applying the research results to the initially-identified specific problem, documenting the application and doing a follow-on critique and evaluation to help gauge success.

These last two major elements are depicted in Figure 7.

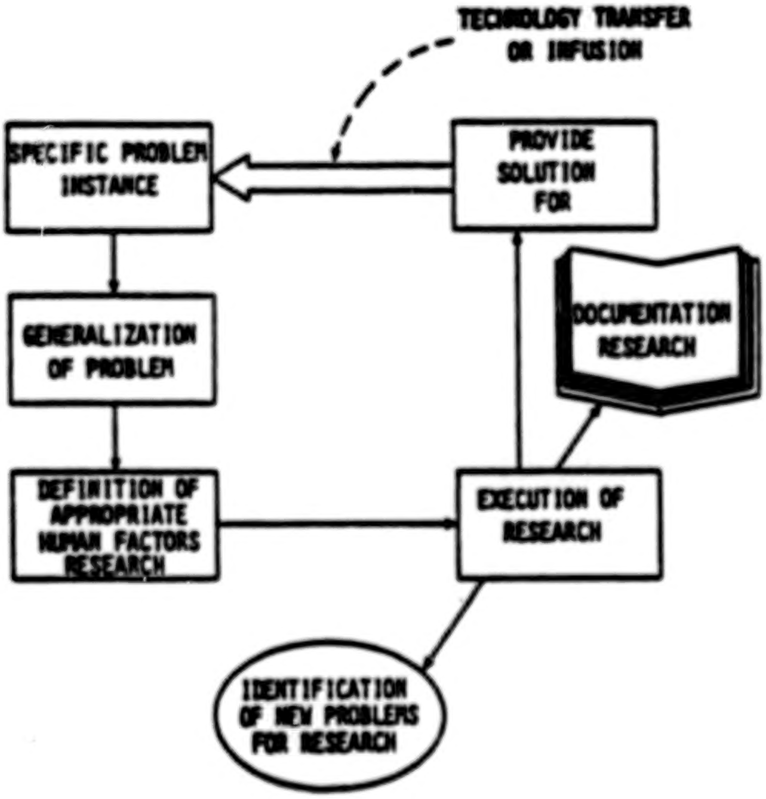

TECHNOLOGY TRANSFER OR INFUSION
SPECIFIC PROBLEM INSTANCE
PROVIDE SOLUTION FOR
GENERALIZATION OF PROBLEM
DOCUMENTATION RESEARCH
DEFINITION OF APPROPRIATE HUMAN FACTORS RESEARCH
EXECUTION OF RESEARCH
IDENTIFICATION OF NEW PROBLEMS FOR RESEARCH

Figure 7

The major components of the Goddard human factors program, namely research, translation and integration and application, are graphically displayed in Figure 8. (This figure is based on one by

Robert Bailey (2)). To date emphasis has been given to the consultant-role of the Human Factors Research Group.

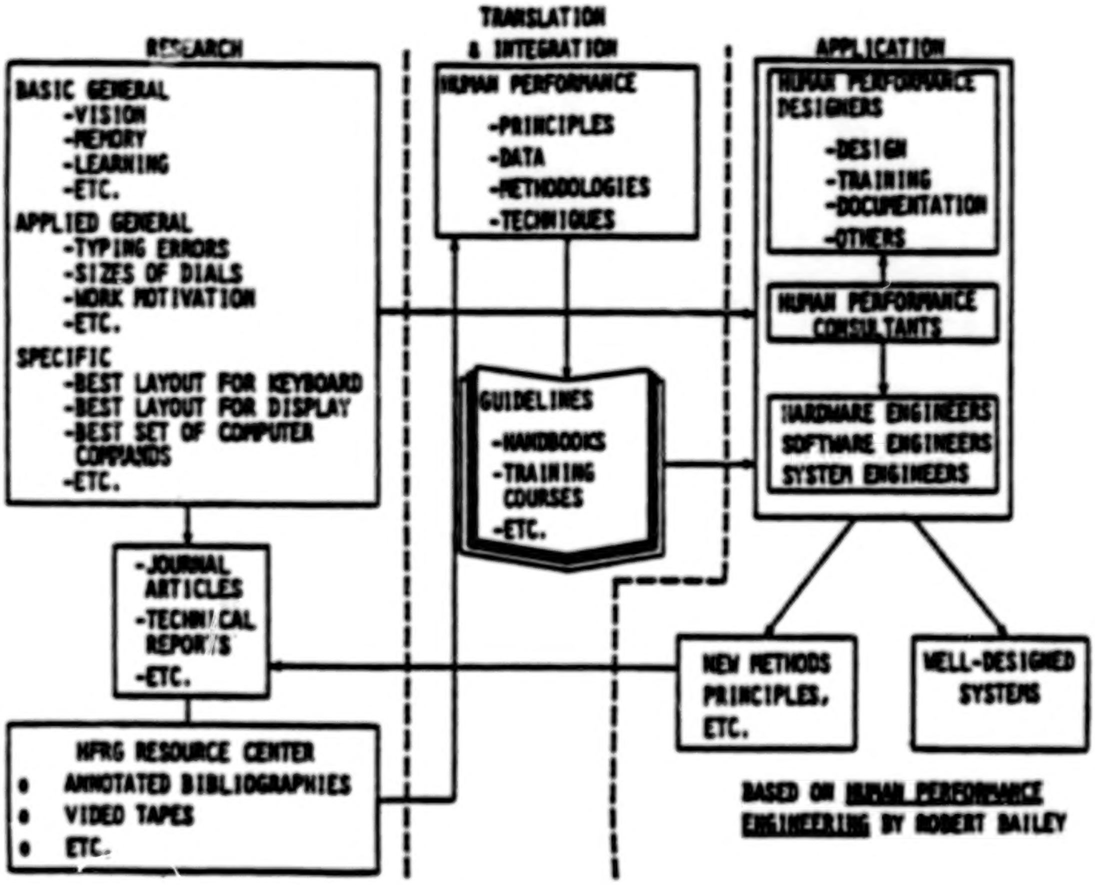

RESEARCH
TRANSLATION & INTEGRATION
APPLICATION
BASIC GENERAL
-VISION
-MEMORY
-LEARNING
-ETC.
APPLIED GENERAL
-TYPING ERRORS
-SIZES OF DIALS
-WORK MOTIVATION
-ETC.
SPECIFIC
-BEST LAYOUT FOR KEYBOARD
-BEST LAYOUT FOR DISPLAY
-BEST SET OF COMPUTER COMMANDS
-ETC.
HUMAN PERFORMANCE
-PRINCIPLES
-DATA
-METHODOLOGIES
-TECHNIQUES
HUMAN PERFORMANCE DESIGNERS
-DESIGN
-TRAINING
-DOCUMENTATION
-OTHERS
HUMAN PERFORMANCE CONSULTANTS
HARDWARE ENGINEERS
SOFTWARE ENGINEERS
SYSTEM ENGINEERS
GUIDELINES
-HANDBOOKS
-TRAINING COURSES
-ETC.
-JOURNAL ARTICLES
-TECHNICAL REPORTS
-ETC.
NEW METHODS PRINCIPLES, ETC.
WELL-DESIGNED SYSTEMS
HFRG RESOURCE CENTER
• ANNOTATED BIBLIOGRAPHIES
• VIDEO TAPES
• ETC.
BASED ON HUMAN PERFORMANCE ENGINEERING BY ROBERT BAILEY

Figure 8

It was recognized from the beginning of this effort that in order to be successful the Goddard Human Factor Program had to be a balanced program . Figure 9 illustrated this.

Since the specific problems requiring applied human factors condiderations would eminate from on-going Goddard activities, a two level organization for the Human Factors Research Group was established. Figure 10 illustrates this. The coordinator is responsible for the bi-directional interface, is the source of data/information to the group, and the mechanism for technology transfer to the project.

THE GSFC HUMAN FACTORS PROGRAM IS A BALANCE BETWEEN:

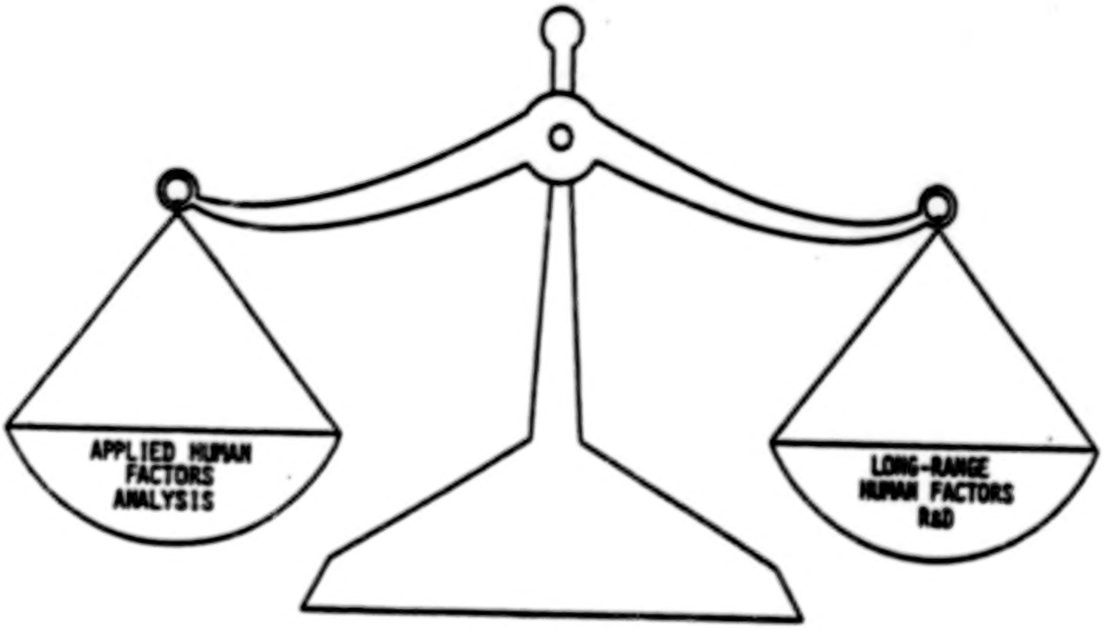

APPLIED HUMAN FACTORS ANALYSIS
LONG-RANGE HUMAN FACTORS R&D

Figure 9

GSFC HUMAN FACTORS RESEARCH
2-COMPONENT STRUCTURE

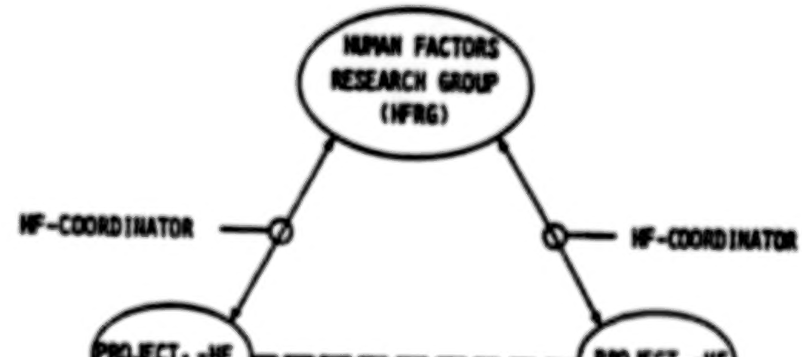

HUMAN FACTORS RESEARCH GROUP (HFRG)
HF-COORDINATOR
HF-COORDINATOR
PROJECT$_1$-HF
PROJECT$_J$-HF

Figure 10

The structure and charter of the Human Factors Research Group outlined in this section is still somewhat experimental. It has been successful so far but is still under study and observation and will be changed when a better approach for conduction Goddards human factors research activities becomes apparent

IV. CURRENT ACTIVITIES AND FUTURE PLANS

This concluding section will give a thumbnail sketch of what we are doing now and what our future plans look like.

Currently, from an applied point-of-view, we are supporting human factors analysis for two major activities. These are the Earth Radiation Budget Satellite (ERBS) and the Mission Planning Terminal (MPT) projects.

For the ERBS project two major areas of concern, the data displays and the control panel, were identified for study. With regard to the displays questions regarding:

- use of colors
- evaluation of project-defined displays
- mixture of graphics and alphanumeric data
- alternative approaches for data display

were to be addressed. With regard to the command panel the group was requested to study such issues as:

- design options
- alternative data input devices
- panel layout
  - format
  - size
  - color
  - resolution
  - text/color consideration

•
•
•

The following illustrate the MPT-related concerns which the group was asked to consider:

- choice of color for normal/emergency displays
- single page data volumes
- data placement on display
- data display time (duration of display)
- appropriate delta times between operator action and system response
- need to echo (confirm) the operator actions on the display
- data input options
- operator alert-mechanisms

•

•

•

Again reports containing the Groups's evaluation of current design goals and specific recommendations is forthcoming.

These two activities are somewhat typical of the applied human factors analysis work currently being undertaken by the Group.

The future looks bright, exciting and challenging. In addition to supporting other applied human factors analysis activities the following are some of the major objective established for the future:

- development of guideline which will ultimately give to system designers and evaluators a comprehensive quantifiable view of systems from a human factors perspective

- development of a uniform methodology to be used by the group in executing its applied human factors analysis and experimentation tasks. Figure 11 is an attempt at stating the methodology problem to be solved. A major question to be addressed is how to quantify human factors objectives

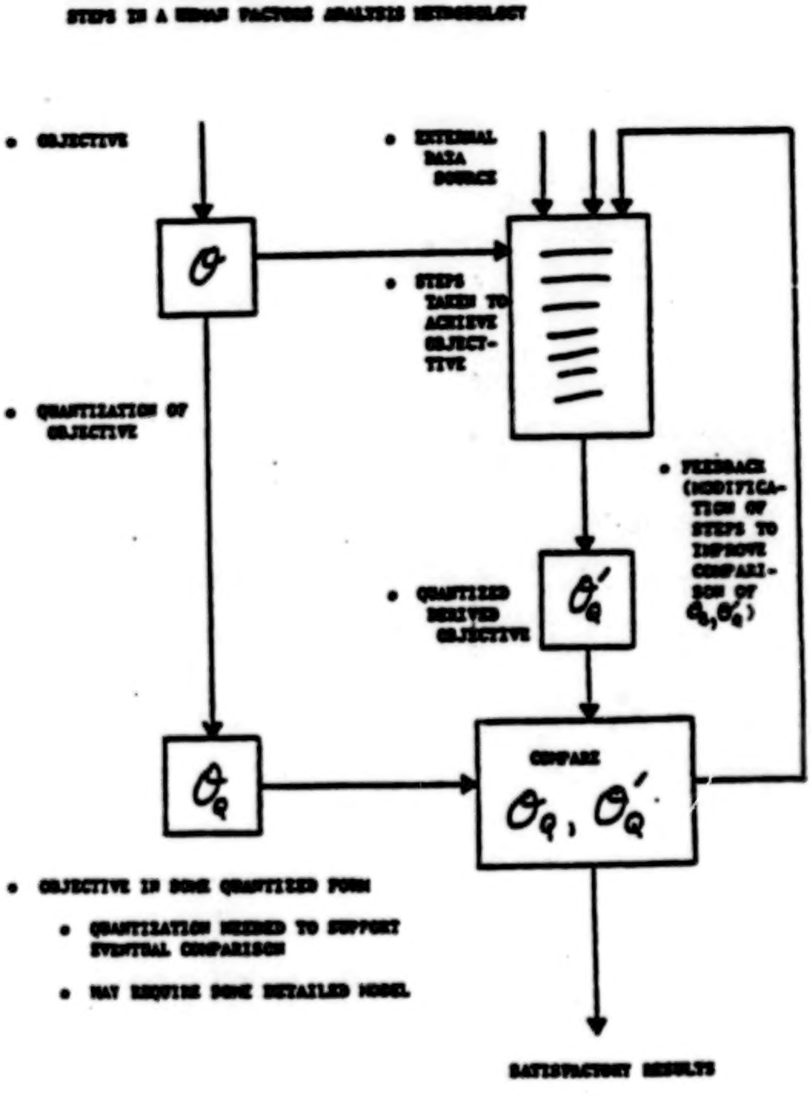

STEPS IN A HUMAN FACTORS ANALYSIS METHODOLOGY
• OBJECTIVE
• EXTERNAL DATA SOURCE
θ
• STEPS TAKEN TO ACHIEVE OBJECTIVE
• QUANTIZATION OF OBJECTIVE
• FEEDBACK (MODIFICATION OF STEPS TO IMPROVE COMPARISON OF θ_Q, θ'_Q)
• QUANTIZED DERIVED OBJECTIVE
θ'_Q
θ_Q
COMPARE
θ_Q, θ'_Q
• OBJECTIVE IN SOME QUANTIZED FORM
• QUANTIZATION NEEDED TO SUPPORT EVENTUAL COMPARISON
• MAY REQUIRE SOME DETAILED MODEL
SATISFACTORY RESULTS

Figure 11

- development of a human factors resource center which will, when completed, be an automated clearing house for pertinent human factors data/information

- development and execution of university-based research programs relating to such activiites as:
    - rapid system prototyping
    - formal representation of man/system interfaces
    - human factors experiment design and evaluation approaches

and

- development of an in-house human factors laboratory. This facility will provide a modern environment for the definition, implementation, testing and evaluation of novel alternative approaches for realizing better systems of the future through applied human engineering. Figure 12 depicts, at a high level, the intent of the proposed human factors environment.

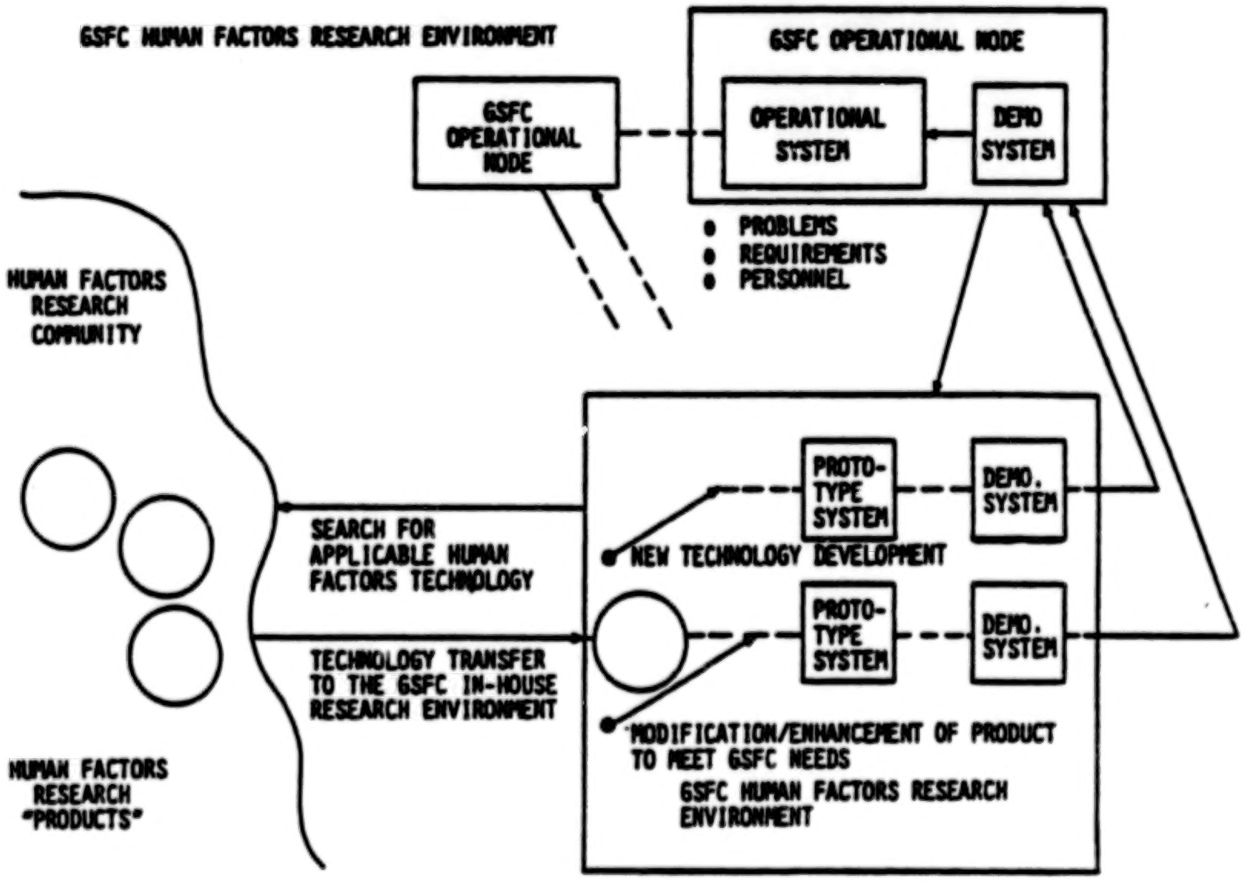

GSFC HUMAN FACTORS RESEARCH ENVIRONMENT
GSFC OPERATIONAL NODE
GSFC OPERATIONAL NODE
OPERATIONAL SYSTEM
DEMO SYSTEM
PROBLEMS
REQUIREMENTS
PERSONNEL
HUMAN FACTORS RESEARCH COMMUNITY
SEARCH FOR APPLICABLE HUMAN FACTORS TECHNOLOGY
PROTO-TYPE SYSTEM
DEMO. SYSTEM
NEW TECHNOLOGY DEVELOPMENT
TECHNOLOGY TRANSFER TO THE GSFC IN-HOUSE RESEARCH ENVIRONMENT
PROTO-TYPE SYSTEM
DEMO. SYSTEM
MODIFICATION/ENHANCEMENT OF PRODUCT TO MEET GSFC NEEDS
GSFC HUMAN FACTORS RESEARCH ENVIRONMENT
HUMAN FACTORS RESEARCH "PRODUCTS"

Figure 12

These objective, among other supported by an expanding cadre of human factors researchers are bing incorporated into a vigorous forward-looking program in human factors which will benefit not only Goddard, in specific, and NASA, in general, but possibly have a positive impact on the field in general.

This then is the Human Factors Research Group - its reason for being, its organization, goals, objectives, current and future activities.

References

1) Rasmussen, Jens, "The Human as a Systems Component" in Human Interaction with Computers, edited by H. T. Smith and T. R. Green, Academic Press, 1980

2) Bailey, Robert, Human Performance Engineering, Prentice-Hall, 1982

GUIDELINES ON ERGONOMIC ASPECTS OF CONTROL ROOMS

DR. CHRISTINE M. MITCHELL
MR. ALEXANDER BOCAST
MS. LISA J. STEWART
GEORGE MASON UNIVERSITY

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Introduction

This session presents preliminary results of the research conducted by George Mason University on Human Factors Aspects of Control Room Design for NASA/Goddard Space Flight Center. The guidelines being developed will address issues in workstation design and layout, health and safety standards for video display terminals (VDTs), some of the less defined issues of display design, staffing of automated settings, and task definitions for human operators in highly automated systems.

This discussion will begin with areas of relatively well-defined knowledge and move into progressively fuzzier areas. This session will begin with anthropometry, workstation design, and environmental design. From there it will move to the automated interface with a discussion of VDTs and displays and of various modes of communication between the system and the human operator using VDTs. Finally the least understood areas of the man-in-the-loop will be examined, first with consideration of the single controller-single task framework and then with consideration of multiple controller-multiple tasks issues. The discussion will conclude with suggestions for a research agenda to increase our understanding of the operational human factors problems of control room design and operation for GSFC.

Anthropometry

Anthropometry is the study of the quantifiable physiological characteristics of human beings within a given population. Anthropometry is essentially empirical, measuring specific attributes of the human body. It is also population specific. Anthropometric studies are meaningful only for a predefined population, say white female VDT operators in civilian agencies in Washington, D.C. From anthropometry, we learn the physical differences, if any, between sexes, among races and nationalities, among age groups, and/or among occupational groups. Anthropometry is purely descriptive, that is, it does not attempt to explain the measurements found.

Because anthropometry considers populations, its observations are phrased as statistical distributions. Fortunately, for dominant genes, characteristics are typically normally distributed through a population. Thus, anthropometric distributions are modelled on a normal or Gaussian distribution, the well-known bell-shaped curve. However, since anthropometry is largely an applied study and its place of application is physical design, anthropometric variance is seldom expressed in terms of statistical variance or standard deviations. Instead, a distribution profile is expressed through percentiles.

In a normal distribution, the two tails of the curve extend asymptotically to zero through infinity. This is, of course, not an accurate description of real measurements of the human body in any population. To provide a practical cut-off, anthropometry provides the critical 5th and 95th percentiles. Ninety percent of the measured population will be included between these percentiles. In practice, good design aims to accomodate this 90% of the target population.

In support of the manned space program, NASA has compiled probably the most comprehensive source book of anthropometric data in the three volume set Anthropometric Source Book. If you wish to know the mean instep size of Korean soldiers or the headwidth of commercial stewardesses, the data are there. The influence of the composition of the population can also be seen. For example, the mean crotch height of Air Force pilots is lower than it is for Army enlistees. A reasonable explanation for this is that the Air Force pilot population has few Blacks while the Army enlistee population has a much higher proportion of Blacks. Since Blacks have proportionately longer legs than do Caucasions, the larger presence of Blacks in the Army population raises the mean crotch height of that population as compared to the pilot population.

The following Figures, taken from Humanscale (Diffrient,Tilley, & Bardagjy,1980), illustrate typical measurement stances. Figures 1 through 4 show the static human body

Diffrient, Tilley, & Bardagjy, 1980

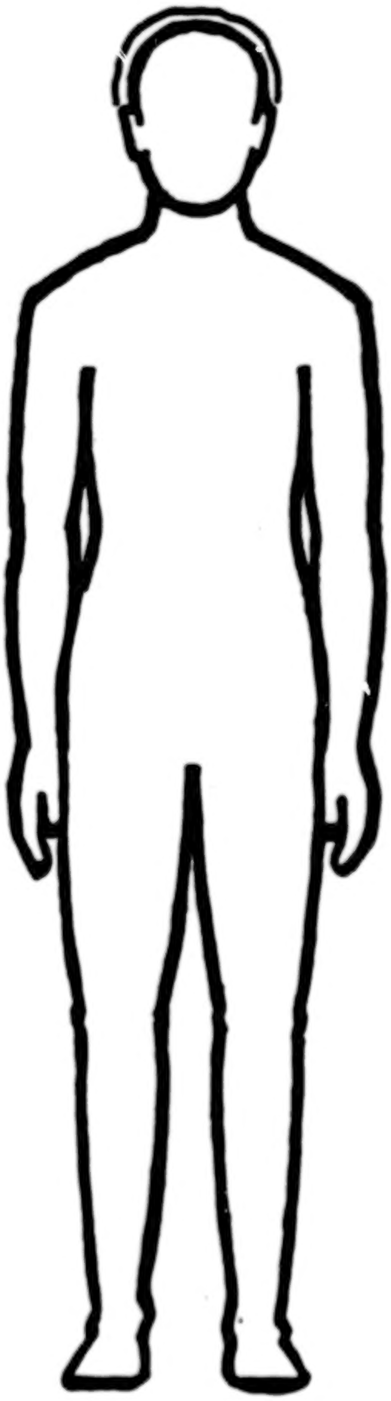


FIGURE 1

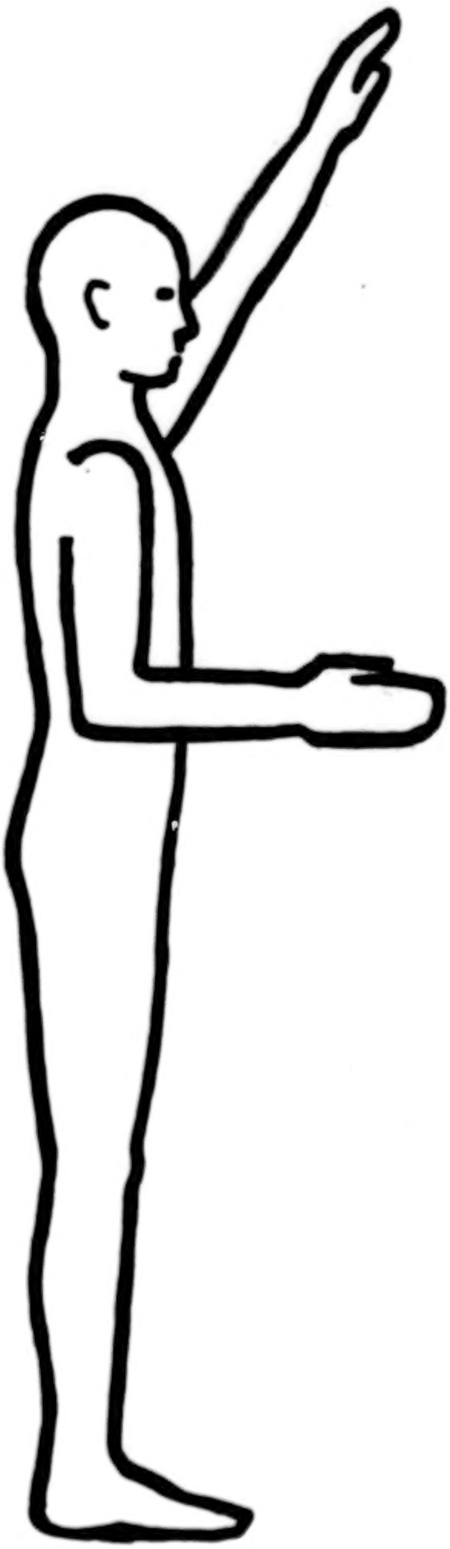


FIGURE 2

Diffrient, Tilley, & Bardagjy, 1980

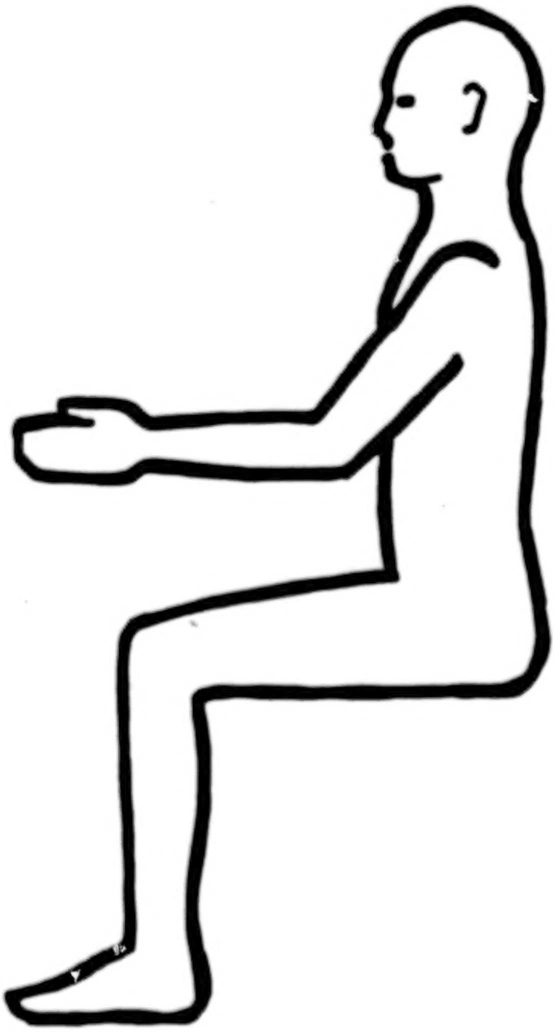


FIGURE 3

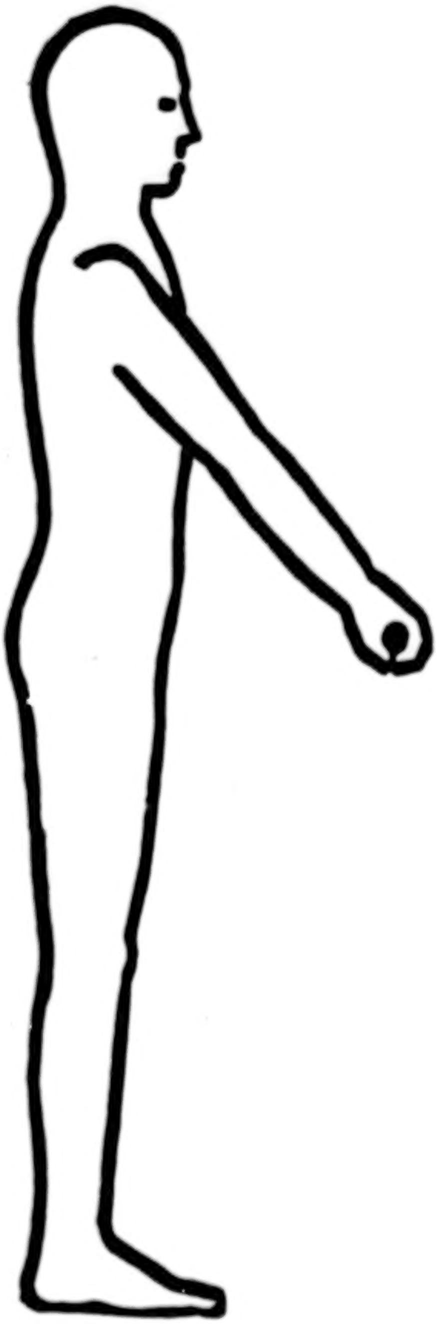


FIGURE 4

Diffrient, Tilley, & Bardagjy, 1980

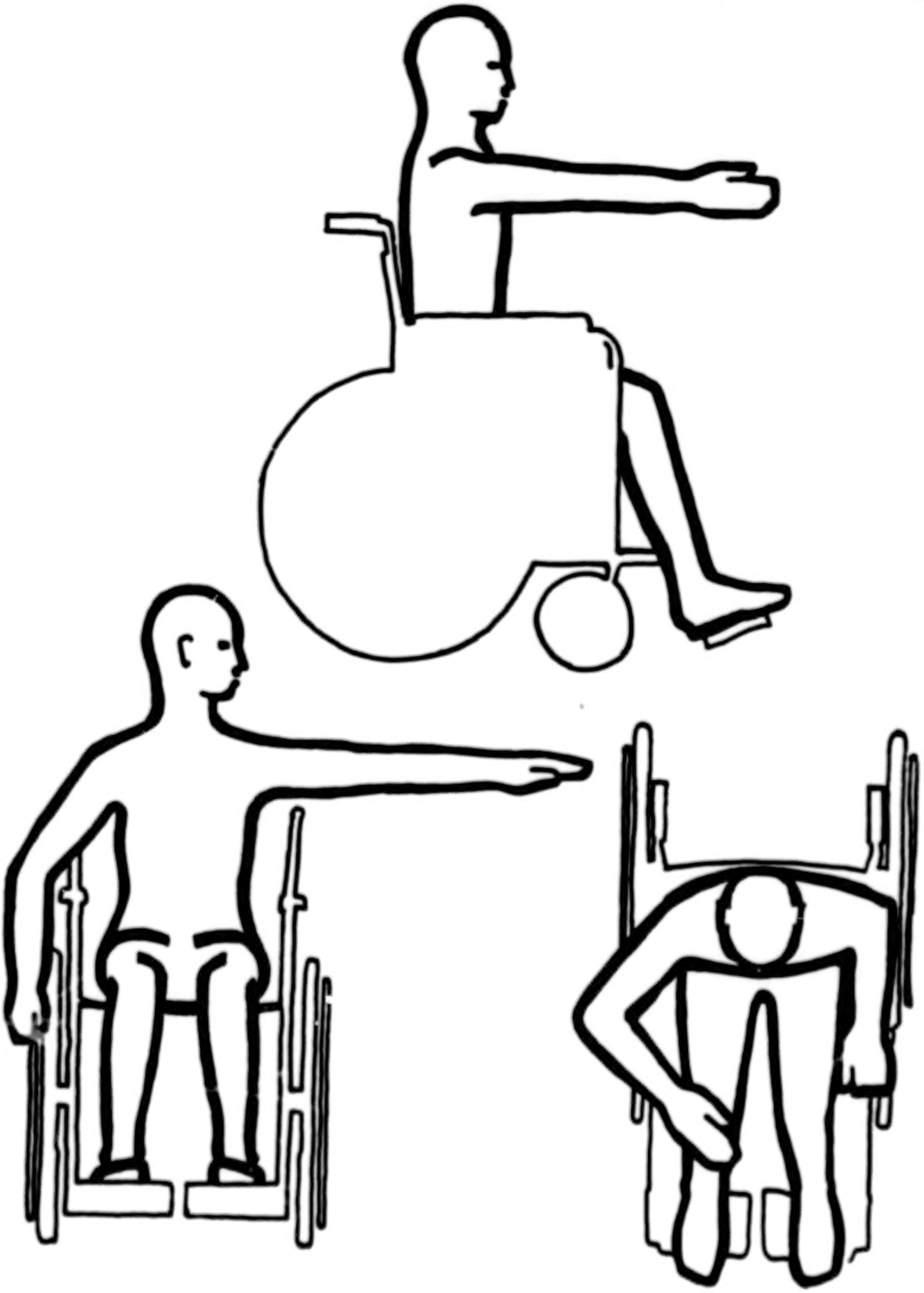


FIGURE 5

with limbs in various angles and extensions. The measurement of these, the anthropometric data, become the baseline database for the design of seating and workstations. Figure 5 shows similar measurement stances for a person in a wheelchair. From Figure 5, it is clear that the geometry of a workstation envelop can change dramatically when a different population is considered.

Figures 6 and 7 envelop the anthropometric data with common everyday tasks. In Figure 6, the geometry of a writing task is formed around the figure—seat height and length, table height and clearance. In Figure 7, the geometry of a driving task is similarly formed around the figure.

In Figures 8 and 9, a control room task geometry is wrapped around the human figure. Figure 9 illustrates the reach diagram. The numbered arcs represent how far the arm in different extensions, i.e. within different horizontal planes and different arm angles, can reach and grasp. The smooth semicircle arc represents the maximum viewing distance for standard displays. (The conjunction of maximum viewing distance and maximum reach, while not perfect, has given rise to the adage, "If you can't touch it, you can't see it", for local workstation design.)

In the following section, such anthropometric data will serve as the foundation for workstation design.

Diffrient, Tilley, & Bardagjy, 1980

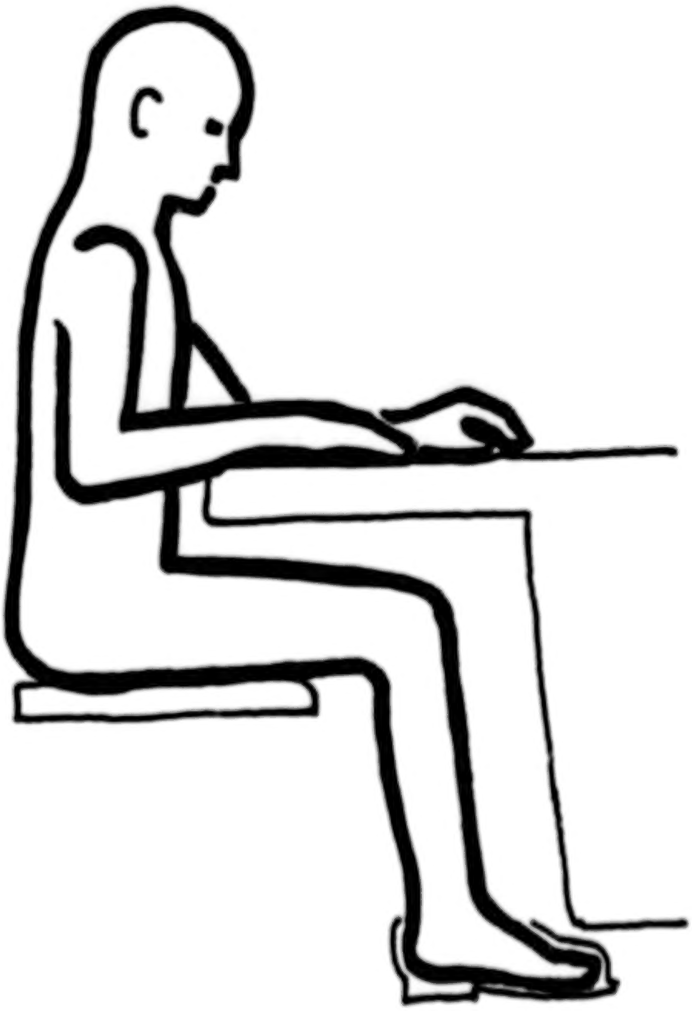


FIGURE 6

Diffrient, Tilley, & Bardagjy, 1980

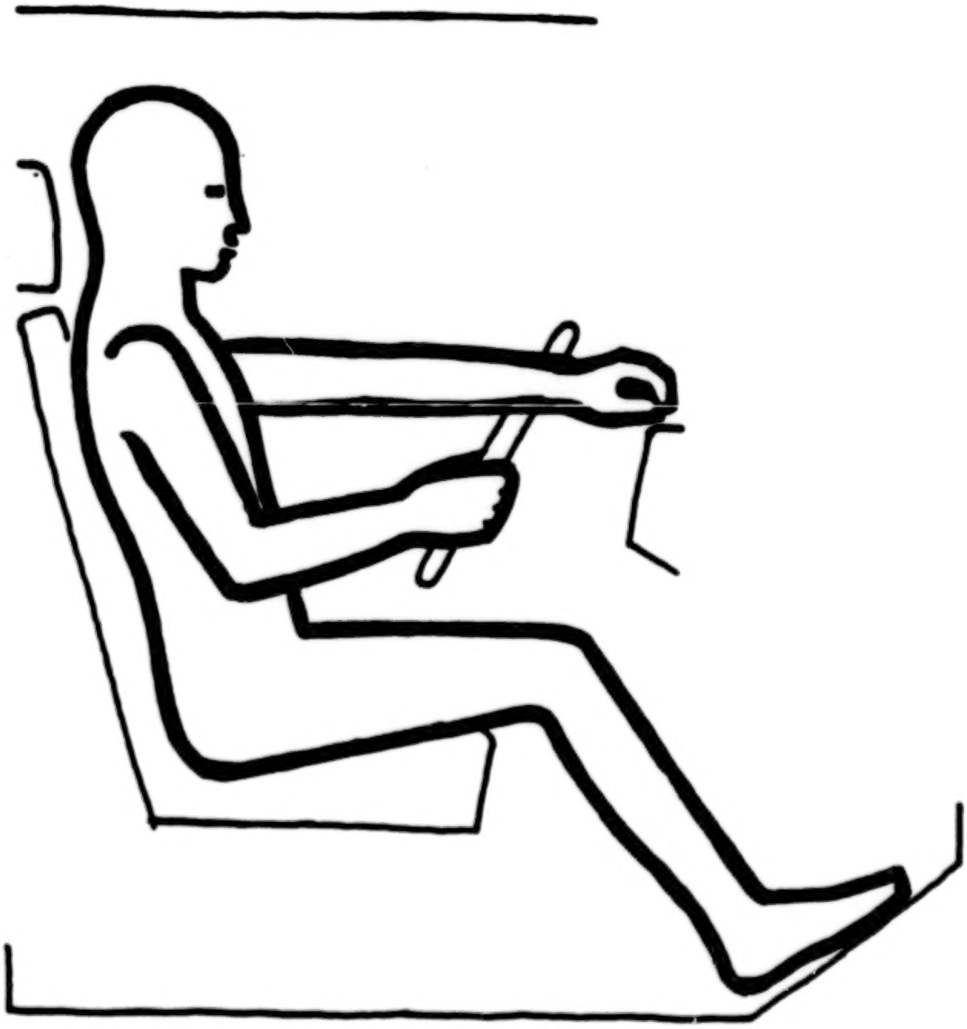


FIGURE 7

Diffrient, Tilley, & Bardagjy, 1980

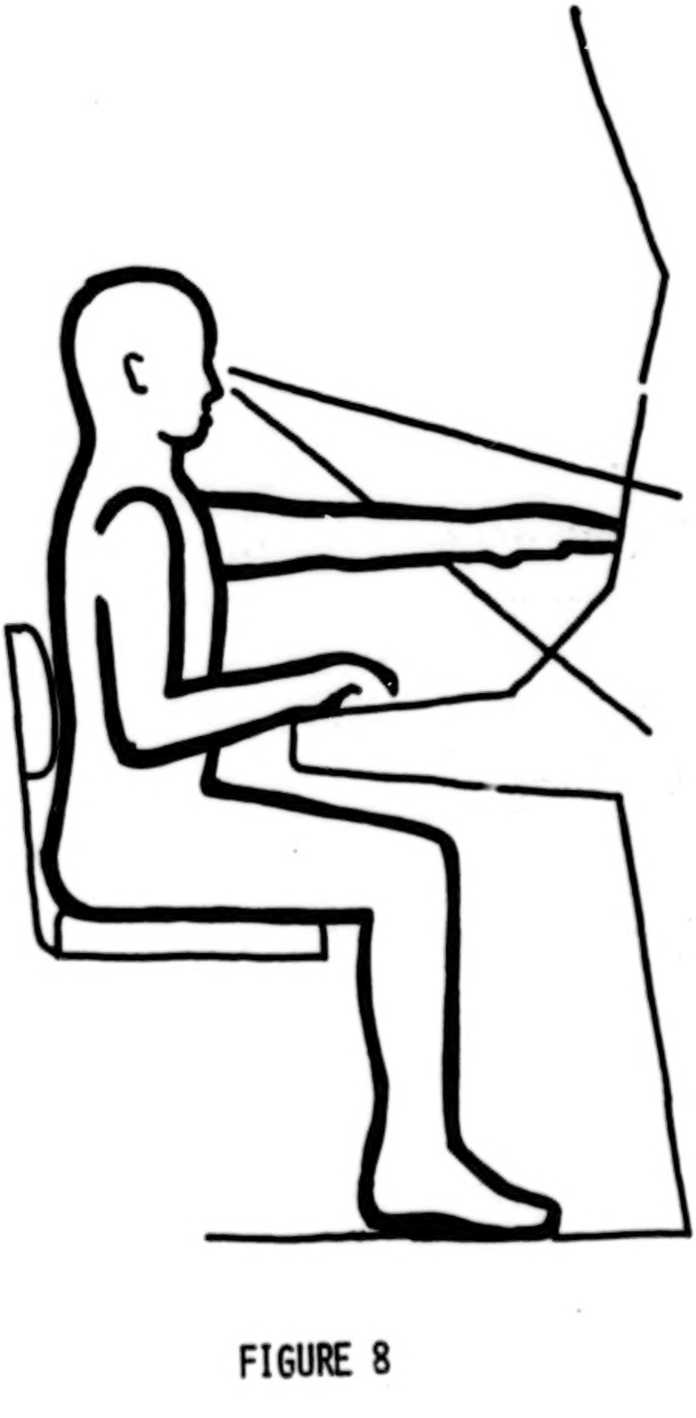


FIGURE 8

Diffrient, Tilley, & Bardagjy, 1980

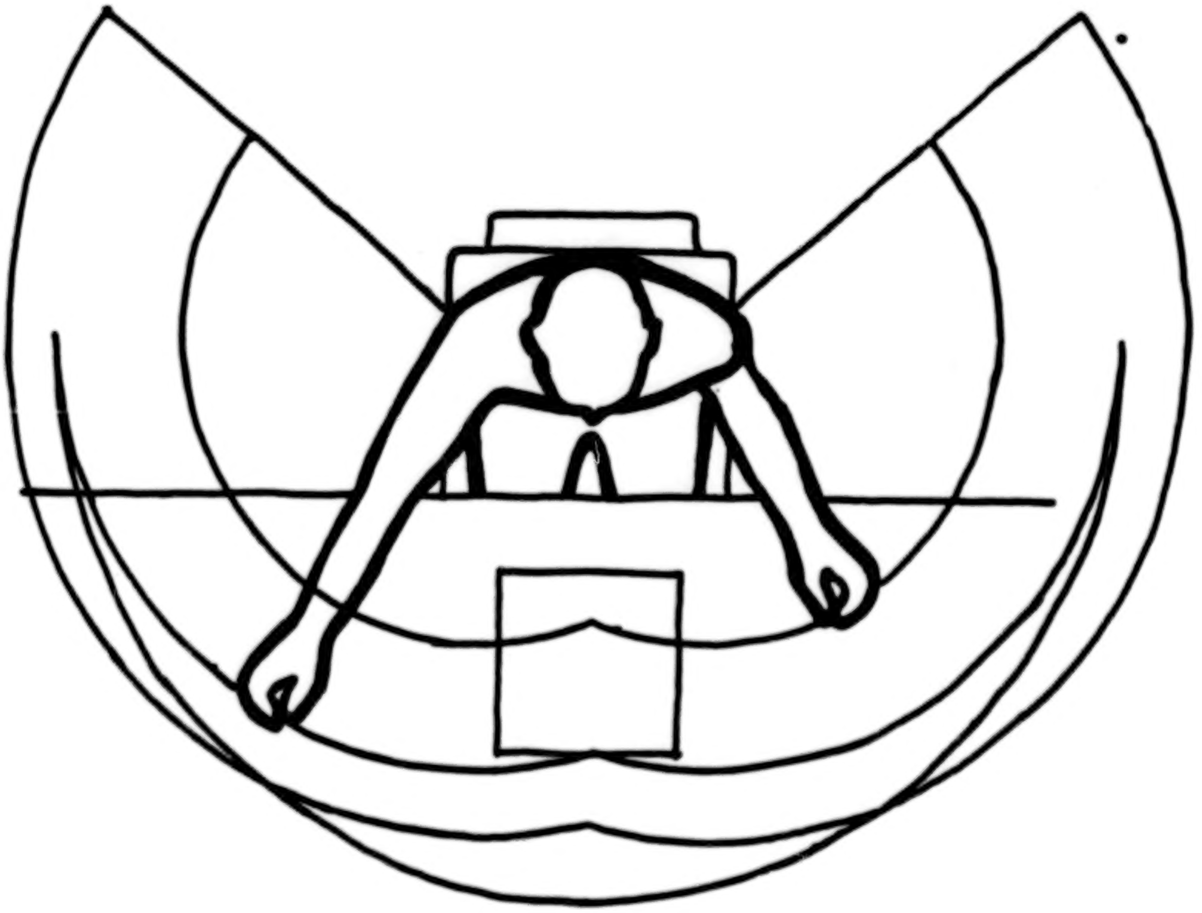


FIGURE 9

Ergonomic Guidelines for Workstation Design, Control Panel Layout, and Workstation Environment

Anthropometric data provides designers with general population characteristics that apply to the design of any equipment or facility. This data has been used as a basis for design by governmental agencies and private industries (Boeing Aerospace Company, 1975; Department of Defense MIL-STD-1472C, 1981; Nuclear Regulatory Commission NUREG-0700, 1981). When anthropometrics are integrated with other ergonomic concerns, e.g., perceptual capabilities and socio-psychological factors, specific guidelines for workstation design result. Although many of the existing guidelines pertain to the specific agency publishing them, most are generalizable and can be applied appropriately to control room design.

An important preliminary guideline for designers is their comprehensive understanding of the tasks being performed, the limits and capabilities of both the equipment and humans, and the functional requirements of the workstation (Anthropometric Source Book, Vol.1,1978) The designer can use several methods to achieve this. A review of all existing documentation is necessary. A human factors tool, task analysis, is another rich source of information. On-site observations of existing or similar systems also lead to valuable insights for the workstation designer.

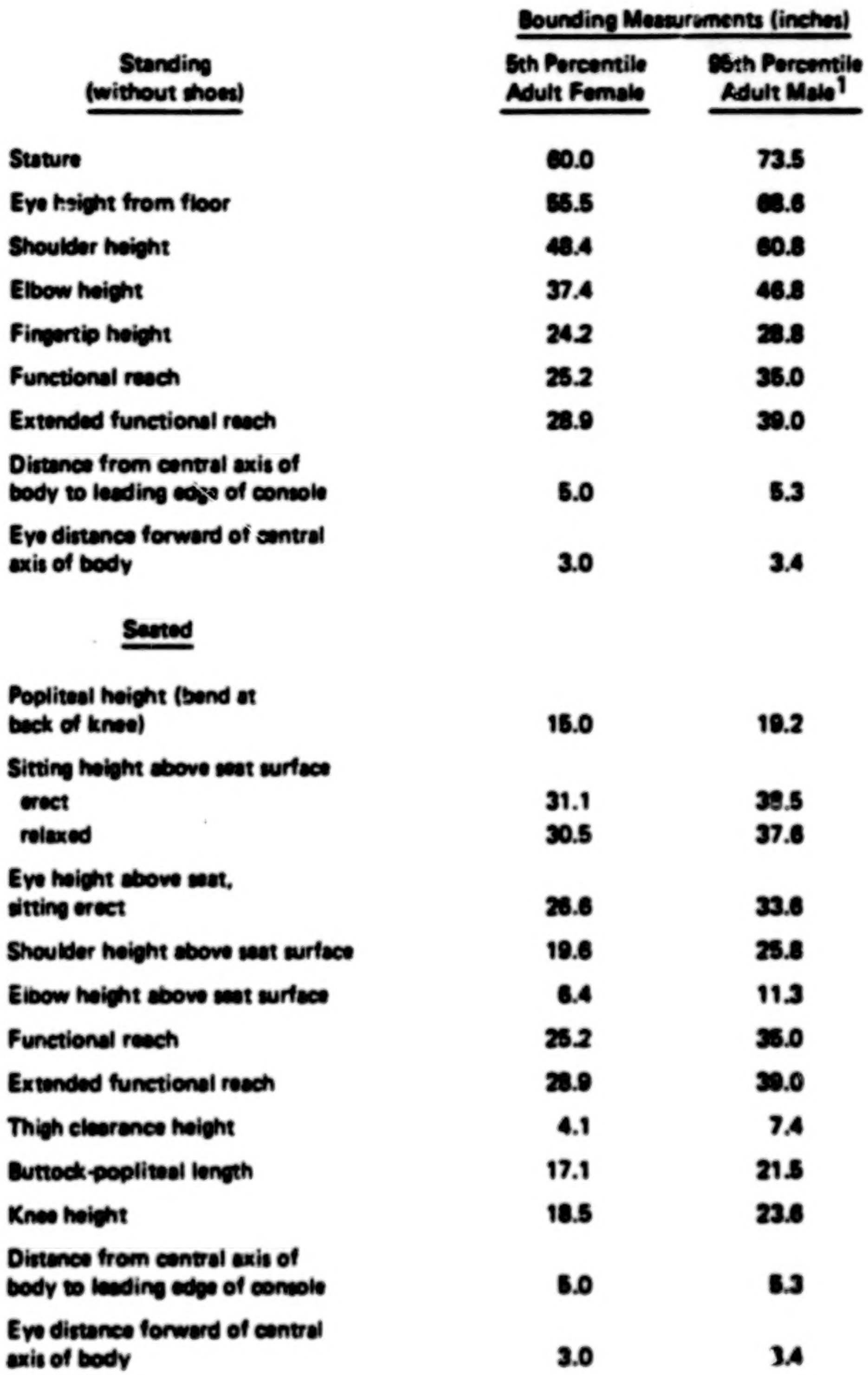
It is strongly recommended (Anthropometric Source Book Vol. I, 1978; EPRI NP-309, 1977; Farrell & Booth, 1975; NUREG-0700, 1981), that the designer be prepared to use workstation mock-ups as part of the design process for testing and evaluation. Mock-ups need not be costly and elaborate to provide adequate feedback to the designer; only minimum configurations are necessary to give insight to designers and users. They allow for necessary revisions and ensure implementation of the best design. Their value is virtually undisputed in the human factors field, and many military agencies require them in the design process.

It is accepted general practice to design equipment and workstations for the 5th and 95th percentile user i.e., the smallest and largest person, respectively, of the user population within accepted confidence limits. If the designer considers both the 5th and 95th percentile user, 95% of all users will be physically able to use the resulting workstation. Anthropometric data, found in Figure 10, provide measurement limits for these end users of the population continuum. Figure 11 supplies a wider range of similar design limiting measurements and is useful because both metric and English scales are used.

The design of a control room workstation may assume that operators are engaged in either seated, standing, or sit-stand operations. For the purpose of this paper guidelines focusing on the seated operator will be presented; these are also most relevant to Goddard. Research has shown that the seated position is superior to a standing one in terms of reducing fatigue. It appears that the arms can perform light work much longer when the operator is seated than when he/she is standing.

The specific guidelines for workstation design that currently exist can be found in several source documents: Cakir, Hart & Stewart, 1980; EPRI NP-1118, 1980; Farrell & Booth, 1975; MIL-H-46855B, 1979; MIL-STD-1472C, 1981; NASA RP 1024, 1978; and NUREG-0700, 1981. An illustration of the typical VDT (visual display terminal) workstation and user can be found in Figure 12; and, while the VDT console is somewhat simpler than a control room console, the illustration provides a useful reference for visualizing the application of design guidelines. Pertinent guidelines for control room workstation design drawn from the aforementioned documents are summarized below.

- o If the operator needs to see over the workstation console, the maximum height to accomodate the shortest user is 45 inches.
- o The controls on the console should be within the reach radius of the operator; the functional reach is between 25-35 inches.



Standing (without shoes)	Bounding Measurements (inches) 5th Percentile Adult Female	 95th Percentile Adult Male[1]
Stature	60.0	73.5
Eye height from floor	55.5	68.6
Shoulder height	48.4	60.8
Elbow height	37.4	46.8
Fingertip height	24.2	28.8
Functional reach	25.2	35.0
Extended functional reach	28.9	39.0
Distance from central axis of body to leading edge of console	5.0	5.3
Eye distance forward of central axis of body	3.0	3.4
Seated		
Popliteal height (bend at back of knee)	15.0	19.2
Sitting height above seat surface		
erect	31.1	38.5
relaxed	30.5	37.6
Eye height above seat, sitting erect	26.6	33.6
Shoulder height above seat surface	19.6	25.8
Elbow height above seat surface	6.4	11.3
Functional reach	25.2	35.0
Extended functional reach	28.9	39.0
Thigh clearance height	4.1	7.4
Buttock-popliteal length	17.1	21.5
Knee height	18.5	23.6
Distance from central axis of body to leading edge of console	5.0	5.3
Eye distance forward of central axis of body	3.0	3.4

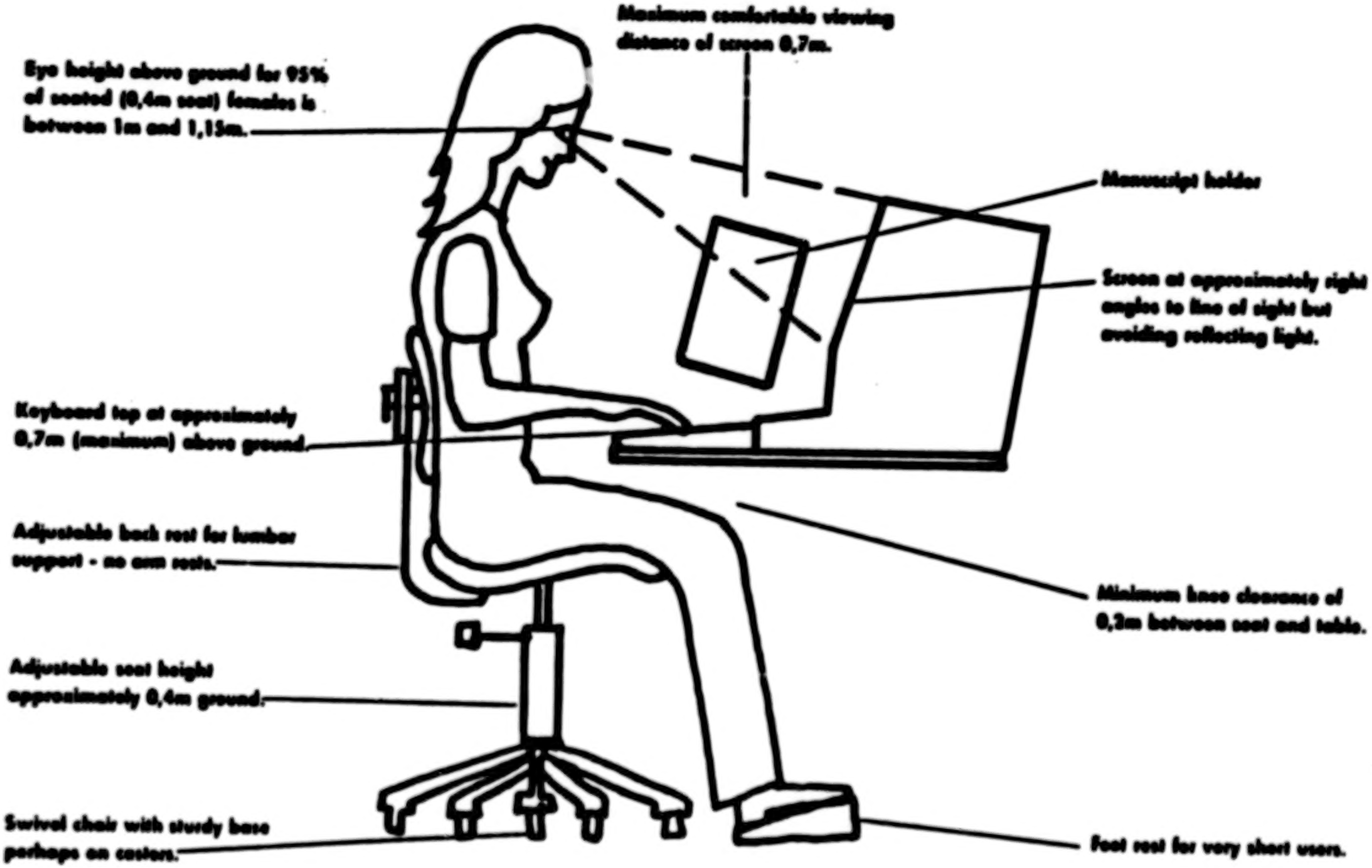
Anthropometric data used to set limits for equipment dimensions.

Figure 10 - NUREG-0700, p. 6.1-14, 1981.

ANTHROPOMETRIC DATA FOR COMMON WORKING POSITIONS

	PERCENTILE VALUES IN CENTIMETERS			
	5th PERCENTILE		95th PERCENTILE	
	MEN	WOMEN	MEN	WOMEN
1. WEIGHT – CLOTHED (KILOGRAMS)	58.6	48.8	90.2	74.6
2. STATURE – CLOTHED	168.5	156.8	189.0	178.7
3. FUNCTIONAL REACH	72.6	64.0	86.4	79.0
4. FUNCTIONAL REACH, EXTENDED	84.2	73.5	101.2	92.7
5. OVERHEAD REACH HEIGHT	200.4	185.3	230.5	215.1
6. OVERHEAD REACH BREADTH	35.2	31.5	41.9	37.9
7. BENT TORSO HEIGHT	125.6	112.7	149.8	138.6
8. BENT TORSO BREADTH	40.9	36.8	48.3	43.5
9. OVERHEAD REACH, SITTING	127.9	117.4	146.9	139.4
10. FUNCTIONAL LEG LENGTH	110.6	99.6	127.7	118.6
11. KNEELING HEIGHT	121.9	114.5	136.9	130.3
12. KNEELING LEG LENGTH	63.9	59.2	75.5	70.5
13. BENT KNEE HEIGHT, SUPINE	44.7	41.3	53.5	49.6
14. HORIZONTAL LENGTH, KNEES BENT	150.8	140.3	173.0	163.8
	PERCENTILE VALUES IN INCHES			
1. WEIGHT – CLOTHED (POUNDS)	129.1	107.6	198.8	164.5
2. STATURE – CLOTHED	66.4	61.8	74.4	70.3
3. FUNCTIONAL REACH	28.6	25.2	34.0	31.1
4. FUNCTIONAL REACH, EXTENDED	33.2	28.9	39.8	36.5
5. OVERHEAD REACH HEIGHT	78.9	73.0	90.8	84.7
6. OVERHEAD REACH BREADTH	13.9	12.4	16.5	14.9
7. BENT TORSO HEIGHT	49.4	44.4	59.0	54.6
8. BENT TORSO BREADTH	16.1	14.5	19.0	17.1
9. OVERHEAD REACH, SITTING	50.3	46.2	57.9	54.9
10. FUNCTIONAL LEG LENGTH	43.5	39.2	50.3	46.7
11. KNEELING HEIGHT	48.0	45.1	53.9	51.3
12. KNEELING LEG LENGTH	25.2	23.3	29.7	27.8
13. BENT KNEE HEIGHT, SUPINE	17.6	16.3	21.1	19.5
14. HORIZONTAL LENGTH, KNEES BENT	59.4	55.2	68.1	64.5

Figure 11 - MIL-STD-1472C, p. 45, 1981.


Maximum comfortable viewing distance of screen 0,7m.
Eye height above ground for 95% of seated (0,4m seat) females is between 1m and 1,15m.
Manuscript holder
Screen at approximately right angles to line of sight but avoiding reflecting light.
Keyboard top at approximately 0,7m (maximum) above ground.
Adjustable back rest for lumbar support - no arm rests.
Minimum knee clearance of 0,2m between seat and table.
Adjustable seat height approximately 0,4m ground.
Swivel chair with sturdy base perhaps on casters.
Foot rest for very short users.

Typical dimensions for a VDT workstation.

Figure 12 - Cakir, Hart & Stewart, p. 188, 1980.

- Controls should be set back from the front edge of a console to prevent accidental activation. A minimum distance of 3 inches is recommended.
- If a VDT display is used, the screen should be placed at a right angle to the operator's line of sight (approximately 15 degrees tilt from the horizontal line of sight).
- The optimal distance for viewing displays, especially VDT displays, is 20 inches.
- When writing surfaces are required for the console, it is recommended they be a minimum of 16 inches deep and 24 inches wide.
- If the operator is using a keyboard, its top should be at a minimum of 27 inches from the ground; if other work surfaces are being used, their tops should be 29-31 inches from the ground.

When focus is centered on the needs of a seated operator in a workstation, two aspects of design are very important. One is the provision of sufficient leg and foot room so the operator can remain comfortably seated. The other important design consideration is the piece of equipment the operator is seated in—the chair. The chair should be designed to complement the task and the user's needs. If the operator is comfortably seated, chance of fatigue and stress is reduced. The likelihood of error due to awkward, uncomfortable positioning is also reduced. The following list summarizes the guidelines pertaining to the seated operator from the above mentioned source documents.

- The space needed for knee room should be a minimum of 18 inches deep.
- The minimum distance for knee clearance between the seat and table is 8 inches.
- Footrests for short users should be provided, and if a console that extends to the floor is being used, a kickspace 4

inches high and 4 inches deep should be provided.

- The chair should provide mobility for the operator; it should swivel and have casters.
- Because the optimum angle between chair seat and back for office tasks is 100 degrees,chairs should have adjustable backrests. It is further recommended that the seat bottom be adjustable to heights between 15 and 18 inches from the floor.
- The chair seat should be at least 17 inches wide and 15-17 inches deep; and should have a downward sloping front edge so the backs of the operator's knees and thighs are not compressed.
- The seat and backrest are should have at least 1 inch of cushioning.
- When the operator's task is data entry arm rests should not be used; when the task involves a long-term seated behavior like monitoring, arm rests should be provided.
- A heel catch on the chair should be provided. One that is circular and 18 inches in diameter is recommended.

It is important when designing a workstation to consider the overall picture: the task, the personnel involved, the surrounding equipment, and all of the necessary interfaces. Reference manuals and procedures documents should be easily accessible to the operator. EPRI NP-1118, Vol. 3, (1980) recommends that a rolling cart be used to store these documents and to provide a surface on which to place references when performing the task. There should be a minimum of 50 inches separating the front edge of one equipment row and the back of the next. The operator needs to be able to get into and out of the workstation. It is recommended that he/she have a maneuvering space at least 30 inches wide and 36 inches deep. Operators must also be aware of the adjustable features of their equipment; and, most importantly, they need to know how to use these features. There are many other workstation-peripheral design considerations that exceed the scope of this paper. The documents referenced here will provide the reader with a more detailed review of workstation design guidelines.

Control Panel Layout

In a command and control setting, the operator's focal point in the workstation is the command panel. The function of this workstation component makes it the most important piece of equipment there. The physical layout of the panel largely determines the effectiveness of its operational use. As would be expected, several ergonomic guidelines exist pertaining to the physical content and layout of command panels.

Command panels have two major features—displays and controls. There are many different kinds of each, and the designer must make a choice based on function and task requirements. Figure 13 lists five common displays and shows what tasks they are best suited for. A good display presents the information to an operator in an easily understood form. When precise, real-time information is needed a digital counter display is best used. If the operator needs to make a relational judgement among a few discrete conditions, moving pointer and trend recorder displays are appropriate. When the task requires an input of some setpoint value, as might be needed in an automatic control system, digital counters and moving pointers best display the necessary information. If the operator is tracking the system over time while controlling it, moving pointer and trend recorder displays are best used to provide the needed information. Indicator status lights are best suited to display qualitative information (i.e., on/off, normal/abnormal).

When designers choose displays for the command panel, they should consider other factors that potentially influence the display effectiveness. The surrounding environmental illumination will affect the illumination levels of the displays themselves. A proper contrast will be necessary for the operator to see the displayed information. The viewing angle of displays should be considered to minimize possibilities for glare. The viewing distance is another important factor, affecting the scale and numeral size of the displays.

RELATIVE EVALUATIONS OF BASIC SYMBOLIC INDICATOR TYPES (ADAPTED FROM VAN COTT AND KINKADE, HUMAN ENGINEERING GUIDE TO EQUIPMENT DESIGN)

For	Counter is	Moving pointer is	Moving scale is	Chart Recorder is	Trend Recorder is
Quantitative reading.	Good (require minimum reading time with minimum reading error).	Fair	Fair	Poor (difficult to read and separate individual values)	Fair (supplemental scale has same drawbacks as moving pointer indicator)
Qualitative and check reading	Poor (position changes not easily detected).	Good (location of pointer and change in position is easily detected).	Poor (difficult to judge direction and magnitude of pointer deviation).	Fair (if all parameters are clustered, ok, otherwise not).	Good (if only comparing two or three parameters)
Setting	Good (most accurate method of monitoring numerical settings, but relation between pointer motion and motion of setting knob is less direct).	Good (has simple and direct relation between pointer motion and motion of setting knob, and pointer-position change aids monitoring).	Fair (has somewhat ambiguous relation between pointer motion and motion of setting knob).	N/A	N/A
Tracking	Poor (not readily monitored and has ambiguous relationship to manual-control motion).	Good (pointer position is readily monitored and controlled, provides simple relationship to manual-control motion, and provides some information about rate).	Fair (not readily monitored and has somewhat ambiguous relationship to manual-control motion).	Poor (not easy to differentiate individual parameters to monitor their changes over time)	Good (if only have two or three parameters which the operator is tracking).

Figure 13 - EPRI NP-1118, p. 3-12, 1980.

The other major command panel feature is the controls, and again the designer has a wide range of choice. The task requirements help determine the best control choices, and Figure 14 illustrates several control types and the functions for which they are best suited. When starting and stopping devices are required, push buttons and toggle switches should be used. If the operator needs to select one of several discrete options or to set the control along a continuous quantitative range, several controls can be appropriately used (as shown in Figure 14). When the operator is continuously controlling a simple system, knobs, thumbwheels, and levers are the best kinds of controls to use. If the task is to input large amounts of data to a system, keyboards should be used. Several other factors affect the choice of proper controls. The operator needs selection, verification, and feedback information, and the controls used should provide it. The space available, both in the surrounding environment and on the panel, affects the choice of controls. Another important factor to consider is control-display compatibility. The operator should be required to perform a minimum of decoding and translation between controls and displays. Labelling should be clear and consistent, and controls should be appropriately located near their corresponding displays.

From an ergonomic standpoint, there are several guiding principles (EPRI NP-1118, 1980) for arranging control and command panels, either in terms of several panels e.g., nuclear power plant control rooms, or within one panel e.g., satellite system control rooms. When an operator has to act and react in a fixed sequence, panels can be arranged sequentially. Left-to-right and top-to-bottom sequences are most common as they conform to American population stereotypes. A sequential arrangement will minimize the movements required of the operator, an important consideration for time critical operations. It is also recommended that controls used in sequence be grouped together. The designer may determine that the operator's visual search time needs to be reduced for certain tasks and therefore opt for a frequency of use arrangement. The most frequently used controls and displays are placed near the center of the optimum

COMMON TYPES OF CONTROLS AND THEIR PREFERRED FUNCTIONS (ADAPTED FROM McCORMICK, HUMAN FACTORS IN ENGINEERING AND DESIGN)

Control Device	Activation	Discrete Setting	Continuous Setting	Continuous Control	Data Entry	Comments
Pushbutton	X					Direct feedback if backlit
Toggle Switch	X	X				Good for 2 or 3 options
Rotary Selection Switch		X				Compact for multi-options
Banks of Pushbuttons		X	X			Direct feedback if backlit
Knobs		X	X	X		
Thumbwheels		X	X	X		
Levers			X	X		
Keyboards					X	

Figure 14 - EPRI NP-1118, p. 3-15, 1980.

visual and manual reach area of the panel so as to reduce the visual search time. A third principle for layout, a functional arrangement, is the most common one in practice. Here, all controls and displays that are used to perform a function are grouped together on a panel. An importance arrangement, where the most important controls and displays are placed within the operator's optimal visual and reach distance, can also be used for layout. Another approach to layout is graphic or pictoral arrangements, more commonly known as mimic panels. All related controls and displays are connected by visible lines drawn on the panel to show specific arrangements. This approach has two disadvantages; mimics require a lot of panel space and are difficult to modify once implemented.

In determining the control panel layout, the designer can greatly benefit from using mock-ups. He can use the tool of link analysis with differing dependent criteria to create layouts and then test and evaluate the arrangements. This step in the design process will ensure that the operator is provided with an optimally arranged control panel, thus increasing productivity and reducing likelihood of error.

Workstation Environment

Several environmental factors of the workstation, which can enhance or degrade the performance of the man/machine interface, must be considered in the design process. Many environmental ergonomic guidelines exist to ensure safe, comfortable, and efficient workspaces (Farrell & Booth, 1975; MIL-STD-1472C, 1981; NUREG-0700, 1981). Most published guidelines focus on the illumination, temperature, and noise levels within a workstation environment. Adequate lighting is needed so the operator can see to optimize task performance. Figure 15 gives recommended illumination levels determined by the task being performed. Designers should also be aware that in order to reduce operator fatigue, eyestrain, and reading errors, the levels of illumination should not vary greatly over the workstation, and shadows and glare should be avoided. Indirect or diffuse lighting and the reduction of distracting contrasts will help eliminate these problems. The temperature levels recommended by the published guidelines are fairly uniform and summarized below: (MIL-STD-1472C, 1981; NUREG-0700, 1981)

Work Area or Type of Task	Task Illuminance, footcandles		
	Minimum	Recommended	Maximum
Panels, primary operating area	20	30	50
Auxiliary panels	20	30	50
Scale indicator reading	20	30	50
Seated operator stations	50	75	100
Reading:			
• Handwritten (pencil)	50	75	100
• Printed or typed	20	30	50
Writing and data recording	50	75	100
Maintenance and wiring areas	20	30	50
Emergency operating lighting	10	As above for area/task	

(Source: Illuminating Engineering Society of North America, *IES Lighting Handbook*, 1981 Application Volume.)

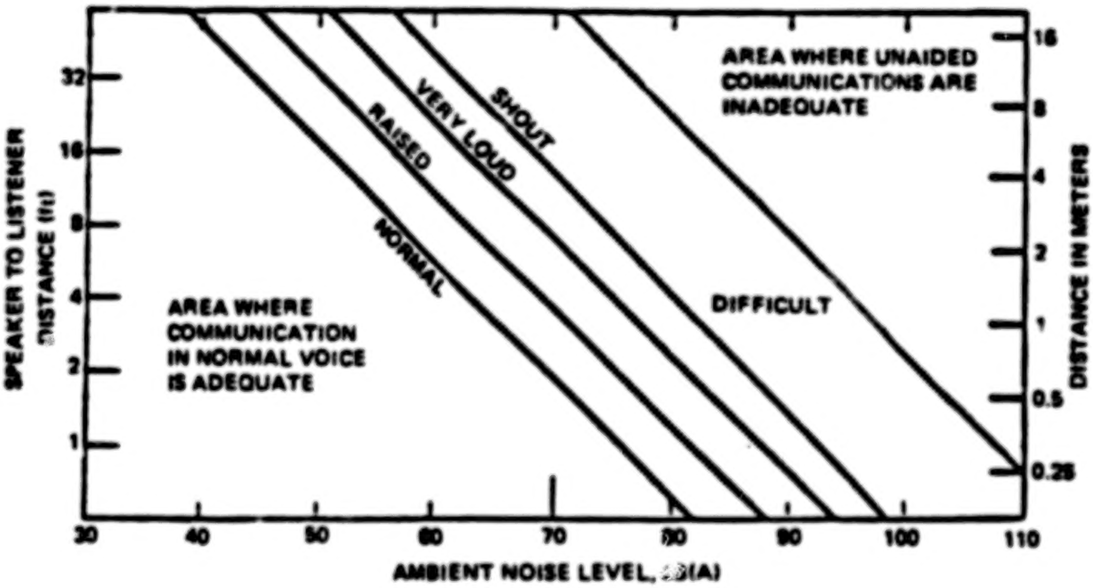
Illumination levels.

Figure 15 - NUREG-0700, p. 6.1-46, 1981.

- The heating levels should not fall below 65 degrees F.
- The air conditioning levels should not exceed 85 degress F.
- Cold or hot air should not discharge directly onto personnel.
- The humidity level within the work area should range from 45% to 50% and, as the temperature rises, it should decrease some. The humidity level should not vary greatly during a workshift.
- To reduce fatigue adequate ventilation should be provided, and it is recommended that 30^3 ft. of air per minute per person be introduced to the workstation.

Auditory noise levels also need to be considered by the designer. Excess noise can be detrimental to the operator's performance. It can be irritating, fatiguing, and if loud enough, unsafe. It is therefore recommended that the background noise level not exceed 65 decibels. Figure 16 illustrates this by showing the necessary voice levels for effective communication as a function of the background noise level and distance from speaker to listener. As shown, it rapidly becomes difficult to communicate effectively as background noise levels increase.

One environmental concern that is only lightly touched on by the published ergonomic guidelines is the physical workstation atmosphere. In a series of evaluative reports on existing nuclear power plant control rooms, the Electric Power Research Institute (EPRI NP-309, 1977; EPRI NP-1118, 1978; 1979; 1980) concludes, "This aspect of control room design has an impact on operator performance, although difficult to quantitatively assess . . . equipment and facilities designed with aesthetic considerations in mind are likely to earn the respect and care of user personnel" (EPRI NP-309, 1977). Designers seem to disregard some of these concerns in the rush to get the hardware implemented and functioning. While that is certainly a primary objective, it should not



Voice level as a function of distance between speaker and listener and ambient noise level.

Figure 16 - NUREG-0700, p. 6.1-50, 1981.

be achieved at the expense of ergonomic concerns. Efforts should be made by the designer towards creating pleasant, comfortable, and safe work settings. Workstations, especially those staffed continuously, should be colorful, bright, clean looking and clean smelling. A pleasing atmosphere will lessen the effects of stress and fatigue and improve the psychological state of the operator.

Ergonomic guidelines for workstation design and environment are rapidly becoming accepted tools for the designer of any facility (e.g., NUREG-0801, 1981). Each setting is unique and more likely than not requires some situation-specific design; however, most functionally similar settings (i.e., command and control rooms) have many common elements and can benefit greatly from generalized guidelines. A valuable, integrated ergonomic checklist pertaining to workstation design and environment can be found in Figure 17. This checklist from the book, Visual Display Terminals, (Cakir, Hart, and Stewart, 1980) provides an easy to use and comprehensive set of guidelines. It does not address control panel layout; guidelines pertaining to panel-related issues more closely resemble qualitative principles rather than quantitatively measurable recommendations. Workstation design and environmental recommendations lend themselves more easily to the format of Figure 17. The design of a workstation involves other considerations besides control panel layout and environment, and these other ergonomic concerns are considered next.

(Cakir, Hart, and Stewart, 1980)

SUMMARY OF RECOMMENDATIONS

Desks, Footrests

		YES	NO
1.	Are a sufficient number of work surfaces provided?	▶☐	☐
2.	Are the working surfaces of sufficient size?	▶☐	☐
3.	Are all items of equipment and job aids which must often be manually manipulated within the normal arm reach of the operator, i.e. within reach without requiring movement of the body?	▶☐	☐
4.	Is the desk height between 720 and 750 mm?	▶☐	☐
5.	Is the height of the keyboard above floor level between 720 and 750 mm?	▶☐	☐
6.	Is the surface of the desk matt finished?	▶☐	☐
7.	Is the reflectance of the desk surface:		
	▶ 0,4? (optimum)	▶☐	☐
	▶ 0,5? (acceptable)	☐	☐
	▶ 0,6? (maximum)	☐	☐
8.	Is the height of the leg area sufficient?	▶☐	☐
9.	Is the underside of the desk free of obstructions?	▶☐	☐
10.	Is the leg area at least 800 mm wide to permit unobstructed turning?	▶☐	☐
11.	Is the leg area at least 700 mm deep?	▶☐	☐
12.	Is the leg area shielded against heat from the VDT and other items of equipment?	▶☐	☐
13.	Is adequate space provided for storage of copies, handbooks, documents, personal belongings etc.?	▶☐	☐
14.	Is the leg area free from obstructions such as desk frame spars?	▶☐	☐
15.	Is it possible for the operator to easily re-arrange the workplace, e.g. by changing the positions of the VDT and other items of equipment?	▶☐	☐
16.	Is a footrest provided which covers the entire leg area?	☐	☐
17.	If footrests are used are they adjustable		
	▶ in height?	▶☐	☐
	▶ in inclination?	▶☐	☐
18.	Can the footrest be quickly and easily adjusted to cater for the different body sizes of the operators?	▶☐	☐

FIGURE 17

(Cakir, Hart, and Stewart, 1980)

		YES	NO
19.	Is the surface of the footrest such as to enable comfortable movement of the feet without slipping?	▶☐	☐

Chair

		YES	NO
1.	Does the design of the chair satisfy the requirements of the national standards?	▶☐	☐
2.	Is the chair stable i.e. safe from tipping over? (fivepoint base)	▶☐	☐
3.	If the chair is provided with castors are they self-locking?	▶☐	☐
4.	Is the seating height easily adjustable?	▶☐	☐
5.	Is the seat angle adjustable?	▶☐	☐
6.	Is the front edge of the seat rounded to avoid cutting into the thighs?	▶☐	☐
7.	Is the seat surface padded?	▶☐	☐
8.	Is the height of the backrest adjustable?	▶☐	☐
9.	Can the backrest be adjusted forwards and backwards?	▶☐	☐
10.	Can adjustments be made easily and safely from the seated position?	▶☐	☐
11.	Are the adjustment mechanisms safe against self- or unintentional release?	▶☐	☐
12.	Is there guidance available to the individual operators to help them achieve an optimum adjustment of their chair?	▶☐	☐

Job Aids, Other Items of Equipment

Documents

		YES	NO
1.	Do the documents that are necessary to the task satisfy the requirements of section I as far as		
	▶ character formation?	▶☐	☐
	▶ contrast between characters	▶☐	☐
	▶ and background?	▶☐	☐

(Cakir, Hart, and Stewart, 1980)	YES	NO
2. Are all paper surfaces matt?	▶☐	☐
3. Can all of the information which is relevant to the task be easily read?	▶☐	☐
4. Where appropriate, does the format used on documents such as order, billing forms etc., correspond to the display screen format?	▶☐	☐

Siting of the VDT, job aids and other items of equipment

	YES	NO
1. Are all job aids and items of equipment so positioned that - apart from short-term considerations - the operator may assume an optimum working posture according to the following criteria:		
▶ head inclined forward at an angle of ca 20°	▶☐	☐
▶ spine slightly arched and forward leaning when seen from the side	▶☐	☐
▶ upper arms vertical	▶☐	☐
▶ no twisting of the head and trunk	▶☐	☐
▶ thighs approximately horizontal	▶☐	☐
▶ lower part of the leg approximately vertical	▶☐	☐
▶ sufficient leg room both in height and depth	▶☐	☐
▶ frequent changes of visual object accommodated within an angle of 15-30° relative to the normal viewing direction	▶☐	☐
2. Are all job aids and items of equipment in the visual and working field situated according to frequency of use?		
▶ their frequency of use?	☐	☐
▶ their relation to the way the task is performed?	☐	☐
▶ their importance?	☐	☐

ENVIRONMENTAL CONSIDERATIONS

Lighting

	YES	NO
1. Is the illuminance between 300 and 500 lux?	▶☐	☐
2. Is the operator's field of vision free of direct reflections from the display screen, keyboard, desk, papers etc?	▶☐	☐

(Cakir, Hart, and Stewart, 1980)

		YES	NO
3.	Are there glare sources in the operators field of vision, lights, windows etc?	▶☐	☐
4.	Are the luminaires equipped with prismatic or grid-type glare shields?	▶☐	☐
5.	Is the lighting system equipped with duo- or three-phase switching?	▶☐	☐
6.	Are the VDT workplaces positioned such that the operators line of vision is		
	▶ parallel to luminaires?	▶☐	☐
	▶ parallel to windows?	▶☐	☐
7.	Are the windows fitted with external blinds?	☐	☐
8.	Are the windows fitted with internal blinds?	☐	☐
9.	Are the windows fitted with curtains with a reflectance in the range 0,5 to 0,7?	▶☐	☐
10.	Is the average reflectance of the ceiling greater than 0,7?	▶☐	☐
11.	Is the reflectance of the walls between 0,5 and 0,7?	▶☐	☐
12.	Is the reflectance of the floor about 0,3?	▶☐	☐
13.	Are the lamps fitted with starters to prevent flashing at the end of their useful life?	▶☐	☐
14.	Has the regular cleaning and maintenance of the luminaires been properly considered?	▶☐	☐

Room Climate

		YES	NO
1.	Is the work room air conditioned?	▶☐	☐
2.	Can the room temperature be maintained between 21 and 23°C?	▶☐	☐
3.	Can the relative humidity be maintained between 45 and 55%?	▶☐	☐
4.	Is the speed of air movement less than 0,1m/s		
	▶ at neck height?	▶☐	☐
	▶ at waist height?	▶☐	☐
	▶ at ankle height?	▶☐	☐

(Cakir, Hart, and Stewart, 1980)

	YES	NO
5. Are the individual operators and their neighbours protected against thermal loading from the equipment by		
▶ thermal radiation?	▶☐	☐
▶ warm air flow?	▶☐	☐
6. Have steps been taken to avoid local hot spots, e.g. under desks, in corners etc?	▶☐	☐

Noise

	YES	NO
1. Is the noise level:		
▶ less than 55 dB(A) in task areas requiring a high level of concentration?	▶☐	☐
▶ less than 65 dB(A) in routine task areas?	▶☐	☐
2. Are the equipment noise levels no more than 5 dB(A) greater than the background noise level?		
▶ VDT, e.g. fans, power supply but not the auditory feedback and signals from the keyboard?	▶☐	☐
▶ other items of equipment?	▶☐	☐
3. Is the noise environment free from high frequency tones?	▶☐	☐
4. Is the noise in the VDT room affected by external noise sources, e.g. neighbouring rooms, the outside world?	☐	☐
5. Are there other items of equipment in the workroom, e.g. printers, teletypes, which generate high or distracting levels of noise?	☐	☐

Ergonomics of Visual Display Terminal (VDT) Design

The introduction of computers into the office environment has generated widespread concern about the health and safety of humans whose primary task requires prolonged interaction with computer-based visual display terminals (VDTs). Radl (1980) summarizes some of the problems typically associated with VDT workplaces.

- Many of the screens and keyboards are badly designed. The most unsatisfactory points are: low luminescence level on the display, low contrast between characters and background, flicker of the display, reflections on the screen, and the design of the whole box in such a way that it is often impossible to use in a human-adapted position. In many cases keyboards are connected with the display box and are unnecessarily high and produce light reflections, mainly on the surfaces of the keys.
- Relatively poor workplace design and bad positioning, including mistakes in the illumination, can also be found at many of the present workplaces.
- Also, the illumination conditions at most VDT workplaces are unsatisfactory. There are only general recommendations to avoid glare. Information on how to avoid glare and reflections on the screen is not disseminated. The existing illumination problems are caused by daylight as well as by artificial lighting.
- Eye defects are often the reason for an increase in workload of many persons working with VDTs. These eye defects are not caused by VDT use. Field studies have shown that more than 50% of all German adults have non-corrected eye defects and this is an important loading factor, when these persons work with VDTs.
- In many cases the use of VDTs has forced an increase of information transmission rates between man and and the technical information-processing systems. Normally a new technical and more computerized system with VDT workplaces is installed for economic reasons. Most manufacturers promise in their advertisements to reduce costs by increase in performance of the human-computer system. Therefore all activities during the introduction phase, as well as later, are concentrated on bringing a higher output (meaning an increase of symbols per minute, data per hour or other number of working units per day and employee (Radl et al. 1980)). It is difficult to explain that the main effect of the use of computer and VDT technologies should be to increase not primarily the quantity of information rates at the human-technical information-processing system interface, but the quality of the whole system performance, e.g. through better information selection and handling, through more flexibility of the organization, through better written output and through better and more adaptive reactions of the offices - and last but not least through more humanity at the workplace in the office.
- Many arguments in the discussions about VDT workplaces are emotional. This is understandable, because the VDT has become a negative symbol for anxieties of the employee in the office: anxiety about the technical and organizational changes in the white collar area, anxiety about mass unemployment by the rationalization effects, anxiety about dequalification, and anxiety over more control from the

computer. It is important to know and to try to solve these social problems. But it is also important to separate the ergonomically caused and the socially caused problems in the discussion of the acceptance of VDTs, because each kind of problem needs different measures to be solved.

- VDTs have had very bad publicity in the media. If a problem of their use is discussed in a research report, the papers will generalize it for all sorts of VDT workplaces and they will once again point out how unhealthy and dangerous work with VDTs is.

These concerns have prompted a great deal of discussion, some research, and even some legislation. At the anecdotal level, there was a strike by clerical personnel at the United Nations when word processing equipment was installed. In a similar vein, the U.S. Department of Commerce is thinking of removing its word processing equipment due to operator complaints and concern that the automated equipment is lengthening task time (due one supposes to an increased number of drafts made possible by the word processing systems).

On a more serious note, a number of European governments have or are preparing to take some legislative or regulatory measures to ensure the health and safety of VDT operators. Sweden is the most advanced, having passed legislation which specifies some design aspects of visual display terminals. Germany has proposed standards and safety regulations in which various visual display design parameters are specified. The French have gone one step further; a government decree has placed operators of terminals in the hazardous occupation category. As a result, employers are required to provide additional rest breaks and enhanced medical care for those employees. The European activity has been far greater than that of the U.S. The mose active U.S. agencies are the National Institute of Occupational Safety (NIOSH) and the U.S. military services. NIOSH has just concluded a large study examining health potential of working with VDTs (Human Factors, Vol. 23, No. 4, August 1981). The military services have also extended their interest to include concern for operator stress, performance, and safety (MILSTD-1472C). As more attention has been focused on VDT problems, some basic assumptions have evolved to guide the ergonomic research on VDT design and use. These include Radl (1980):

- Eye discomfort and workload in VDT workplaces can be reduced to or below the level at workplaces without VDTs but with similar tasks. The condition: screen, presentation mode, VDT box, keyboard, the whole workplace and the environmental factors have to be designed as well as possible by existing technologies and following existing recommendations which are the results of ergonomic research and practical experiences.

- It is not generally in question whether to use a VDT or not. But there are many questions and also practical answers on how to design a specific VDT workplace and its environment with respect to man and his specific task at this workplace. Manufacturers and users do not only need our criticism on VDTs and workplaces. They need detailed information on how to make it better.

- Work-time limitations and special break-time regulations for VDT workers are not the optimal way to solve the existing problems. It should not be the main target of ergonomics to compensate for high workload, which is caused by poor working conditions, only by time limitations or by additional break-times. The better measure consists in avoiding the loading factors by human-adapted workplace design and by interesting, non-monotonous tasks.

The basic ergonomic issues have thus far focused on health and safety of the operator. In particular, there has been a good deal of investigation into the possibility of VDT-induced radiation and into the negative aspects of VDT use with respect to both vision and posture. One universal conclusion which is very encouraging is that there is not a radiation hazard associated with VDT use (Murray et al., 1981; Cakir, Hart, and Stewart, 1980). In addition, a number of useful specifications have been developed in relation to VDT lighting requirements, display screen, keyboard design, and work station design.

It should be noted that there are many factors which have received insufficient attention or have been completely neglected. For the most part, these are factors which are poorly defined and whose impact on operator performance is not well understood. For example, psychological considerations such as task difficulty, urgency, or criticality (e.g., air traffice control) are not related to operator stress or fatigue. These are particularly pertinent to real time systems and require additional study. Even though far from complete, the design specifications and guidelines being developed in response to the move toward office automation are applicable to a wider variety of VDT tasks. Incorporation of basic ergonomic standards can improve the workplace and enhance productivity for all VDT operators both in the office and in the control room.

There are a number of sets of guidelines available; a partial list is provided in Figure 18. One easy-to-use reference is given in checklist form by Cakir, Hart, and Stewart (1980). This checklist provides criteria for the selection of a visual display terminal and, where standards exist, recommended standards. The checklist is contained in Figure 19. It should be noted that the recommended standards in this checklist are consistent with those suggested by other authors. The checklist is organized so that in those cases where there is a clear cut standard, tolerance range, or lower bound, the preferred answer is clearly indicated. Properties for which there are currently not clear cut guidelines or whose values are task/user specific are included in order to expand the VDT designer's or purchaser's inventory of specifications.

The checklist sorts the properties into three rough groupings: issues which pertain to the display screen, the keyboard, and to general system requirements. The section on display screen properties includes questions on character formation, coding, and format as well as display screen luminance. Display screen luminance is particularly important as there is a great deal of research that suggests that operator stress and fatigue may in part be attributable to VDTs which fail to meet minimum luminance criteria. This is unfortunate as luminance specifications can be evaluated at purchase and luminance characteristcs fairly easily adjusted after installation. The section on the keyboard outlines some general criteria, some specifics on key characteristics, and some requirements for keyboard design. The final section is a potpourri of general points which should be addressed in purchasing or installing a VDT.

These criteria pertain to what can be thought of as the physical or hardware properties of a computer-based information display. The software or informational properties of displays are equally as important but much less defined. Perhaps as a result, there has been very little research on these issues. One exception is the topic of display coding techniques. These techniques include alphanumeric coding, shape coding,

Guidelines for VDT design

Bailey, Robert W., Human Performance Engineering: A Guide for System Designers, Prentice-Hall, Englewood Cliffs, N.J., 1982.

Banks, W. W. and D. I. Gertman and R. J. Petersen, Human Engineering Design Considerations for CRT-Generated Displays, Idaho National Engineering Laboratory, FCC-SSDC-5610, October, 1984.

Cakir, A. and D. J. Hart and T.F.M. Stewart, Visual Display Terminals, John Wiley & Sons, New York, 1980.

Grandjean, E. and E. Vigliani (Eds.), Ergonomic Aspects of Visual Display Terminals, Taylor & Francis, Ltd., London, 1980.

Ramsey, H.R. and Michael E. Atwood, Human factors in computer systems: A Review of the Literature, NTIS A075-679, 1979.

Shurtleff, Donald A., How to Make Displays Legible, Human Interface Design, La Miranda, California, 1980.

FIGURE 18

(Cakir, Hart, and Stewart, 1960)

THE DESIGN AND OPERATING CHARACTERISTICS OF VDTs

The Display Screen

Character formation

		YES	NO
1.	**Does the screen have a display capacity, i.e. number of available character spaces, that is sufficient for the task?**	▶☐	☐
2.	**If the display capacity is less than the maximum capacity required by the task, is there sufficient display memory?**	▶☐	☐
3.	**Is the display memory accessed by**		
	▶ roll scrolling?	☐	☐
	▶ page scrolling?	☐	☐
	▶ pan scrolling?	☐	☐
4.	**Is scrolling under keyboard control?**	▶☐	☐
5.	**Is the character set sufficient for the task?**	▶☐	☐
6.	**Is the colour of the characters in the display**		
	▶ white?	☐	☐
	▶ yellow?	☐	☐
	▶ green?	☐	☐
	▶ other?	☐	☐
7.	**Is the character height greater than or equal to 3 mm?**	▶☐	☐
8.	**Do the character height and viewing distance ensure a visual angle of at least 16°, preferably 20°?**	▶☐	☐
9.	**If the characters are generated by dot matrix, do the individual dots merge sufficiently well so as to produce a sharp and well defined image?**	▶☐	☐
10.	**Is the resolution of the dot matrix**		
	▶ 5 x 7? (acceptable)	☐	☐
	▶ 7 x 9 or greater? (preferred)	▶☐	☐
11.	**Is the character width 70-80% of the upper case character height?**	▶☐	☐
12.	**Is the stroke width between 12% and 17% of the character height?**	▶☐	☐

FIGURE 19

(Cakir, Hart, and Stewart, 1980)

	YES	NO
13. Is the space between the characters between 20% and 50% of the character height?	►☐	☐
14. Is the row spacing between 100% and 150% of the character height?	►☐	☐
15. Does the VDT permit the display of both upper and lower case characters?	►☐	☐
16 In displaying lower case characters do descenders project below the base line of the matrix?	►☐	☐
17. Is it possible to clearly distinguish between the following characters		
X and K?	►☐	☐
O and Q?	►☐	☐
T and Y?	►☐	☐
S and 5?	►☐	☐
I and L?	►☐	☐
U and V?	►☐	☐
I and 1?	►☐	☐
18. Is it possible to clearly distinguish between the number "0" and the letter "O" (it should be noted that the letter Ø is included in several Nordic alphabets and should not be used to represent the number "0")?	►☐	☐
19. Are the basic characters upright, i.e. not slanted?	►☐	☐
20. Are cursive characters, e.g. italic, available for special coding purposes?	☐	☐
21. Is it possible to adjust the orientation of the screen or the VDT about its vertical axis?	►☐	☐
22. Is it possible to adjust the screen about its horizontal axis? (screen angle)	►☐	☐
23. If the screen is fixed, is it approximately vertical?	☐	☐
24. Is the upper edge of the screen at or below eye height?	►☐	☐
25. Where appropriate, does the visual display format correspond to the format which is used on documents, e.g. order forms?	►☐	☐

(Cakir, Hart, and Stewart, 1980)

Coding, Format

		YES	NO
1.	Is colour available as a means of coding in the display?	☐	☐
2.	How many colours is it necessary to distinguish between		
	▶ 1 - 5?	☐	☐
	▶ 5 - 10?	☐	☐
	▶ > 10?	☐	☐
3.	Is luminance, i.e. selective brightening used as a means of coding in the display?	☐	☐
4.	How many luminance levels it is necessary to distinguish between		
	▶ 2?	☐	☐
	▶ 3?	☐	☐
	▶ >3?	☐	☐
5.	Is it possible to clearly distinguish between the different luminance levels at maximum setting?	▶☐	☐
6.	Is a cursor provided?	▶☐	☐
7.	Is it possible to clearly distinguish the cursor from other symbols on the display?	▶☐	☐
8.	Is it possible to generate graphic symbols via the keyboard?	☐	☐
9.	Is it possible to blink selected parts of the display?	☐	☐
10.	Is the blink rate between 2 and 4 Hz?	▶☐	☐
11.	Is it possible to suppress the repeated blink action of the cursor?	▶☐	☐
12.	Is it possible to display characters of differing size?	☐	☐
13.	Is it possible to display characters of differing style?	☐	☐
14.	Are all displayed symbols unambiguous?	▶☐	☐
15.	If filters are used, are the characters in the display sharply defined?	▶☐	☐

(Cakir, Hart, and Stewart, 1980)

		YES	NO
16.	Is it possible to adjust the orientation of the screen or the VDT about its vertical axis?	▶☐	☐
17.	Is it possible to adjust the screen about its horizontal axis? (screen angle)	▶☐	☐
18.	If the screen is fixed, is it approximately vertical?	▶☐	☐
19.	Is the upper edge of the screen at or below eye height?	▶☐	☐
20.	Where appropriate, does the visual display format correspond to the format which is used on documents, e.g. order forms?	▶☐	☐
21.	Can forms be generated with protected fields?	☐	☐

The display screen and luminance

		YES	NO
1.	Is the character luminance		
	▶ greater than 45 cd/m^2? (minimum)	☐	☐
	▶ between 80 and 160 cd/m^2? (preferred)	▶☐	☐
2.	Is the character luminance adjustable?	▶☐	☐
3.	Do the character images remain sharply defined at maximum character luminance?	▶☐	☐
4.	Is the background luminance between 15 and 20 cd/m^2 under the appropriate office lighting conditions?	▶☐	☐
5.	Is the background luminance adjustable?	▶☐	☐
6.	Is the contrast between the character and background		
	▶ 3 : 1? (minimum)	☐	☐
	▶ 5 : 1? (better)	☐	☐
	▶ 8 : 1 - 10 : 1? (optimal)	▶☐	☐
7.	Is the contrast between the screen background and other items in the working field, e.g. documents, better than		
	▶ 1 : 10? (acceptable)	☐	☐
	▶ 1 : 3 - 1 : 5? (preferred)	▶☐	☐
8.	Are the displayed character images stable?	▶☐	☐

(Cakir, Hart, and Stewart, 1980)

The Keyboard

General criteria

		YES	NO
1.	**Is the keyboard detached from the display screen console, i.e joined by a cable?**	▶☐	☐
2.	**Is the weight of the keyboard sufficient to ensure stability against unintentional movement?**	▶☐	☐
3.	**Is the thickness of the keyboard, i.e. base to the home row of keys**		
	▶ less than 50 mm? (acceptable)	☐	☐
	▶ 30 mm? (preferred)	▶☐	☐
4.	**Is the distance between the underside of the desk frame and the home row of keys on the keyboard less than 60 mm?**	▶☐	☐
5.	**Is the profile of the keyboard**		
	▶ stepped?	☐	☐
	▶ sloped?	☐	☐
	▶ dished?	☐	☐
6.	**Is the angle of the keyboard in the range 5-15°?**	▶☐	☐
7.	**Is the surface of the keyboard surround matt finished?**	▶☐	☐
8.	**Is the reflectance of the keyboard surface (not single keys) between 0,40 and 0,60?**	▶☐	☐
9.	**Is the luminance ratio between the keyboard, screen and documents less than 1:3 or 3:1?**	▶☐	☐
10.	**Is there at least a 50 mm deep space provided for resting the palms of the hands?**	▶☐	☐

Key characteristics

		YES	NO
1.	**Is the key pressure between 0,25 and 1,5 N?**	▶☐	☐
2.	**Is the key travel between 0,8 and 4,8 mm?**	▶☐	☐
3.	**For square keytops is the keytop size between ⊠ 12 and ⊠ 15 mm?**	▶☐	☐

(Cakir, Hart, and Stewart, 1980)

	YES	NO
4. Is the centre spacing between adjacent keys between 18 and 20 mm?	▶☐	☐
5. Are the key legends resistant to wear and abrasion, i.e. are the legends moulded into the keytop?	▶☐	☐
6. Are the keytop surfaces concave so as to improve keyboarding accuracy?	▶☐	☐
7. Are the keytop surfaces such that specular reflections are kept to a minimum?	▶☐	☐
8. Is the activation of each key accompanied by a feedback signal such as an		
▶ audible click?	☐	☐
▶ tactile click?	☐	☐
▶ or snap action?	☐	☐
9. Do the keys have a low failure rate?	▶☐	☐
10. What type of errors might occur as the result of a key failure		
▶ keystroke not registered (contact error)?	☐	☐
▶ keystroke is repeated (jammed key)?	☐	☐
11. If two keys are activated simultaneously, is a warning signal given?	▶☐	☐
12. Is the keyboard provided with a roll-over facility		
▶ 2-key roll-over?	☐	☐
▶ n-key roll-over?	▶☐	☐

Keyboard layout

	YES	NO
1. Does the layout of the alpha keys correspond to the conventional typewriter keyboard layout?	▶☐	☐
2. Does the layout of the numeric keys - above the alpha keys - correspond to the conventional typewriter keyboard layout?	▶☐	☐

(Cakir, Hart, and Stewart, 1980)

		YES	NO
3.	Are the numeric keys grouped in a separate block:		
	▶ as the only numeric keyset?	☐	☐
	▶ or as an auxilliary keyset in addition	☐	☐
	▶ to the keyset referred to under 2?	☐	☐
4.	If an auxilliary numeric keyset is provided, are the keys arranged:		
	▶ as in the calculator layout i.e. 7, 8, 9, along the top row?	☐	☐
	▶ as in the telephone layout i.e. 1, 2, 3 along the top row?	☐	☐
5.	Is the space bar at the bottom of the keyboard?	▶☐	☐
6.	Does the number and type of function keys correspond to the requirements of the task?	▶☐	☐
7.	Does the arrangement of the function keys correspond to the sequences with which the task is carried out?	▶☐	☐
8.	Are keying errors critical as regards the success of the task in question, i.e. rather than merely inconvenient?	☐	☐
9.	Is the colour of the alphanumeric keys neutral, e.g. beige, grey, rather than black or white or one of the spectral colours red, yellow, green or blue?	▶☐	☐
10.	Are the different function key blocks distinct from the other keys by		
	▶ colour?	☐	☐
	▶ shape?	☐	☐
	▶ position?	☐	☐
	▶ distance (spacing)?	☐	☐
11.	Are the most important function keys colour-coded?	☐	☐
12.	Are all keys for which unintentional or accidental operation may have serious consequences especially secure by		
	▶ their position?	☐	☐
	▶ higher required key pressure?	☐	☐
	▶ key lock?	☐	☐
	▶ two handed (two key) chord operation?	☐	☐
13.	Do the function key labels and symbols correspond to the same functions on other keyboards used e.g. typewriters or other VDTs at the same workplace?	☐	☐
14.	Are user-programmable function keys provided?	☐	☐

(Cakir, Hart, and Stewart, 1980)

Additional VDT and System Characteristics

		YES	NO
1.	Is the power dissipation from the VDT as low as possible?	▶☐	☐
2.	Is the VDT resistant to knocks and vibration?	▶☐	☐
3.	Is the operator secure against electrical accident even when tampering with the VDT?	▶☐	☐
4.	Does the VDT satisfy the requirements of all national and local safety standards?	▶☐	☐
5.	Are the operators and cleaning staff aware of which cleaning materials may be used without causing damage to the screen, housing and other components of the VDT?	▶☐	☐
6.	Is there sufficient maintenance access to both the VDT and VDT workplace?	▶☐	☐
7.	Are there any user-serviceable repairs, e.g. fuse changes, that can be quickly and easily carried out by the operator?	☐	☐
8.	Are the electrical supply cables and other services to the VDT and workplace adequately secured and concealed?	▶☐	☐
9.	Has the voltage supply to the VDT system been stabilised against fluctuations in supply voltage, e.g. due to variations in mains voltage, peak loads etc?	▶☐	☐
10.	Is the operator provided with a warning signal in the event of system or VDT malfunction		
	▶ audible alarm?	▶☐	☐
	▶ visual alarm?	▶☐	☐
	▶ other?	☐	☐
11.	Is the operator provided with a warning in the event that the VDT is no longer able to register keystrokes, e.g. when the VDT memory storage is filled?	▶☐	☐
12.	Will security procedures be necessary?	☐	☐
13.	How is the operational status of the VDT, e.g. if the terminal is in send, receive or queue mode, made known to the operator:		
	▶ no indication?	☐	☐
	▶ flashing light indicator?	☐	☐
	▶ continuous light indicator?	▶☐	☐
14.	Is the response time of the system sufficiently short during peak working times?	▶☐	☐
15.	If the response time is likely to vary appreciably, is the operator given an indication of waiting times?	▶☐	☐

(Cakir, Hart, and Stewart, 1980)

	YES	NO
16. If several terminals share a common transmission line to the computer, can each terminal transmit and receive information independently of the status of the other terminals on the line?	▶ ☐	☐
17. Is it necessary to consider special precautions, e.g. special carpeting or a copper grid carpet underlay, to safeguard against the discharge of static electricity to the VDT chassis?	☐	☐

color coding, blink coding, and such miscellaneous considerations as size, depth, line type (solid, dashed, etc.), brightness, line width, motion, and focus or distortion.

There have been numerous empirical studies comparing coding techniques; however, the results are often task specific. Ramsey and Atwood (1979) caution that a great deal of the current knowledge, in addition to possibly being task specific, is relatively old and was developed for contexts other than computer-generated displays. Ramsey and Atwood (1979) give a synopsis on coding techniques (Figure 20).

Alphanumeric coding, the most common technique, is most accurate for identification tasks and acceptable for search tasks. The use of geometric symbols to represent information is called shape coding. This type of coding is fairly unique to computer-generated displays and as a result there is limited research which is generally task specific. In shape coding, care must be taken to ensure that the users can discriminate between the shapes; thus, shapes must be distinct and not very numerous (i.e., it is recommended that the total number of shapes be kept below fifteen). Color coding is an attractive alternative in computer-generated displays. There is some research that indicates that users prefer color even when there is no quantitative evidence that color improves performance. In general, color coding—either redundant or nonredundant—yields better performance than static achromatic coding techniques for search tasks. Ramsey and Atwood (1979) caution, however, that the performance advantage may be quite small and not worth the cost of color displays. Blink coding has been found to be extremely effective in detection tasks. However, large amounts of blinking data or displays which do not permit the user to suppress the blinking may contribute to operator fatigue. Although there is evidence that a human can discriminate between as many as four blink rates, research strongly suggests that there be only one blink rate.

Other techniques include size of displayed object, depth, line type, brightness, and reverse video. All these methods of coding have limited utility, but designers must be

CODING TECHNIQUES

(Ramsey and Atwood, 1979)

Coding Method	Comments
Alphanumeric Coding	Alphanumeric coding is best for absolute identification, but may involve problems of size (coding usually is accomplished by adding additional symbols, which take up space on the display), confusability of similar symbols, learning of associated meanings, and sometimes superimposition of coded symbols.
Shape coding	Shape coding is useable for both search and identification tasks. The use of meaningful shapes or geometric symbols is widespread, but has received little empirical study. A key issue is symbol discriminability.
Color coding	Relevant color coding -- redundant or nonredundant -- generally yields better performance than other coding methods in both search and identification tasks, except that alphanumeric coding yields better identification accuracy. Users tend to prefer color even when there is no performance advantage, and possibly when the overall effect on performance is negative.
Blink coding	Blink coding is effective as an inclusion or exclusion code for target detection tasks, but can adversely affect reading performance if user cannot match scan rate to blink rate. Blink coding helps most with high density displays. Although users can discriminate up to four blink rates, blink coding should probably be restricted to a binary code (1 class flashing, 1 static). In this case, optimal flash rate is probably 3-4 Hz.
Misc.: (size, depth, line type,(solid, dashed) brightness, reverse video).	

FIGURE 20

cautious about ensuring discriminability as well as over use—too many shades or an inability to suppress attention focusing techniques may contribute to the cognitive load on the user.

Beyond these types of issues there is very little which can help system designers lay out information on a display. There are "rules of thumb" which include such principles as logical sequencing, spaciousness, relevance, consistency, grouping, and simplicity. However, they often are given as platitudes and lack sufficient information to allow designers to apply them adequately. It is clear that psychological research is needed to produce a unifying conceptual framework in this area.

There has been some work in the area of human-computer dialogue. In designing a human-computer dialogue, the issue of initiative must be addressed. Who initiates an exchange is important. It has been found that computer-initiated dialogue is best for naive or casual users with few exchanges. More sophisticated users prefer the user control that user-initiated dialogue provides. Although there are design costs associated with it, a mixed mode system which allows the user to select the type of dialogue is probably preferred. Some of the properties of human-computer dialogue are given in Figure 21.

Flexibility is a measure of the number of ways the user can accomplish a given function. There is some evidence which suggests flexibility is helpful for expert users. This is not the case for intermediate or beginning users who tend to adopt a satisficing strategy, learning only enough commands to accomplish exactly what they need. Complexity and power are concepts related to flexibility. Complexity is a measure of the number of options available to the user at a given time. There has been little research in this area. There is some evidence that too much complexity, particularly when it is due to a large amount of irrelevant data, is detrimental to performance. The extreme on the opposite side is that deep but sparse hierarchic structuring, though reducing complexity, is also a detriment to performance. Display complexity is an

PROPERTIES OF HUMAN - COMPUTER DIALOGUES

(Ramsey and Atwood, 1979)

Dialogue Property	Description	Comments
Initiative	Initiative is concerned with whether the user or the computer initiates the individual information transactions within the dialogue. If the computer asks questions, presents alternatives, etc., and the user responds, the dialogue is "computer-initiated". If the user inputs commands without such computer "prompting", the dialogue is "user-initiated". "Mixed initiative" and "variable-initiative" dialogues are also possible.	Computer-initiated dialogues are preferable for naive users or trainees, and for casual users. Computer-initiated dialogue allows reliance on passive, rather than active, vocabulary, implicitly teaches the user a "system model", and allows use of the system by a user who has not yet internalized such a model. Computer-initiated dialogue is also satisfactory for experienced users if use involves few transactions or system response is very fast. The latter usually implies a "smart"terminal. A slow, computer-initiated dialogue is very disruptive to the frequent. experienced user. See the later section on "response time". For most systems, designers should consider allowing the user to select either dialogue mode.
Flexibility	Flexibility is a measure of the number of ways in which a user can accomplish a given function. High flexibility can be achieved by providing a large number of commands, by allowing the user to define or redefine commands, etc.	There is evidence that nonprogrammer users adopt a "satisficing" strategy with respect to flexible dialogues. That is, they tend to utilize known methods for solving a problem even when the system provides less cumbersome methods, known but not yet learned by the users. There is also evidence that more flexible dialogues degrade performance (especially by increasing error rates) of relatively inexperienced users. Thus, highly flexible dialogues may be undesirable except for experienced and/or sophisticated users.
Complexity	Complexity is a measure of the number of options available to the user at a given point in the dialogue. Low complexity can be achieved by using few commands, or by partitioning the commands so that the user selects from a small set at any given time.	The effects of dialogue complexity on performance are unclear. It seems reasonable to expect that there is some optimal level of complexity for a particular task and user type, with degraded performance resulting from significantly more or less complex dialogue structure. There is evidence which suggests that a large number of redundant or irrelevant commands impairs user performance, and that extreme simplification" of the dialogue by hierarchic structuring is also detrimental.

FIGURE 21

Dialogue Property	Description	Comments
Power	Power is the amount of work accomplished by the system in response to a single user command. In a dialogue with powerful commands, the user may accomplish, with a single command, an operation which would require several commands in a system with less powerful commands.	Obviously, the power of the commands must somewhat correspond to the user's needs, which may vary over time and users. In some application areas, a large range of command power is possible and use of relatively high-power commands can be very effective (e.g., matrix operators in a mathematical system). If power is achieved by using powerful commands and facilities instead of less powerful, but more basic commands, the result is a reduction in generality of the system. The MICA study found this to be a significant factor in system rejection by both managers and technical personnel. On the other hand, provision of powerful commands in addition to a more basic set tends to increase dialogue complexity. One possible solution is to partition the dialogue so the less sophisticated user is exposed to a sub-set of commands.
Information load	Information load is a measure of the degree to which the interaction absorbs the memory and/or processing resources of the user.	In most tasks, user performance is adversely affected by information loads which are either too high or too low.

FIGURE 21 CONTD.

important issue and merits additional research.

The final property related to flexibility and complexity is power. Power is the amount of work accomplished by one user command. A powerful human-computer dialogue allows users to accomplish a great deal with one or two "high level" commands. There is a feeling among managers that a powerful system tends to confuse users. Because power is often confounded with high complexity or a lack of generality, the issue of power may not be so easily resolved. As with initiative, the best system is probably one which has a mix of commands, some low level and some quite powerful.

Ramsey and Atwood (1979) recount that design folklore which says "flexibility is good, complexity is bad, power is good". They note that this rule of thumb is simplistic and that a good deal of further research is needed on these issues particularly for specific user types and task domains.

The final characteristic on which a human-computer dialogue may be evaluated is information load. This is a measure of the cognitive load that the dialogue imposes on the user. Ramsey and Atwood (1979) note that there is no evidence that existing knowledge of the measurement and effects of information load is being applied to system design. In fact, information overload is one of the most common problems cited in conjunction with information displays, particularly in control rooms (Seminara et al., 1979). The evidence is that user performance is affected by either too much or too little information. There are numerous techniques for reducing information load. They include: use of displays, more powerful commands, more natural languages, and less operator input.

In addition to the properties of human-computer dialogues, there are guidelines specifying, to some extent, the dialogue types as well as appropriate task domains and user populations for application. Ramsey and Atwood (1979) provide a succinct summary of dialogue types (Figure 22). The question-and-answer dialogue is computer-initiated and appropriate for naive or inexpert users; it is not appropriate for intermediate or

TYPES OF INTERACTIVE DIALOGUES

(Ramsey and Atwood, 1979)

Dialogue Type	Description	Comments
Question-and-Answer	Computer asks a series of questions, to which user responds.	Inherently computer-initiated. For totally naive user, this is probably the most error-free dialogue type. This approach rapidly becomes cumbersome as the user gains experience.
Form-filling	Computer presents form with blanks. User fills in blanks.	Computer-initiated. Faster than ordinary question-and-answer dialogue, because user provides several responses in a single transaction. When user input is dominated by parameter values, rather than commands, this approach is often best. Other than casual use requires terminal with tabbing feature. Under some circumstances, a significant proportion of syntactic data entry errors may be detected if terminal has provision for imposing constraints on data by field.
Menu Selection	Computer presents list of alternatives, and user selects one or more.	Inherently computer-initiated. Can be used for command construction as well as data base search. Very natural dialogue if response-time criteria are satisfied and "point-in" selection device (e.g., light pen, touch panel) is used.
Function Keys With Command	User indicates desired action by depressing keys, each of which represents a command, command modifier, or parameter value.	User-initiated, but with keyboard as memory aid. Can be computer-initiated if "programmable" keyboard or tutorial displays are used. Often appropriate when user input is dominated by commands, rather than parameter values. Appropriate for naive user only if command syntax is very simple and/or computer-initiated form is used; otherwise requires training. Constant presence of all commands and modifiers may make it difficult for user to learn appropriate model (e.g., hierarchical structure) of command language, if language is not simple.
User-initiated Command Language	User types commands, perhaps using mnemonic abbreviations.	Acceptable approach for well-trained user who has fully internalized model of system function and language syntax. Otherwise error-prone and sometimes frustrating. Usually preferred by system designers and programmers, who tend to satisfy these criteria. Often applied uncritically by them to systems in which user does not satisfy criteria.

FIGURE 22

Dialogue Type	Description	Comments
Natural Language	Dialogue is conducted in user's natural language (e.g., English)	Can be user- or computer-initiated or mixed initiative. Fairly high-powered natural language capabilities are now achievable. Cost is very high, however, since the system requires an extensive "knowledge" of the application area in order to understand user inputs. Development of such a data base is definitely a nontrivial task, and is not for unsophisticated designers. "Natural" language may not be the most "natural" dialogue type for many applications (e.g., engineering drawing, mathematics).

FIGURE 22 CONTD.

expert users. Form filling dialogue is also computer-initiated and is more expeditious than question-and-answer. It is appropriate for many data entry tasks, particularly those which provide interactive syntatic checking. A third computer-initiated dialogue is menu selection. Assuming adequate response time, this type of dialogue is appropriate for a wide range of users: naive, intermediate, and expert but casual system users. For expert and frequent users, good design suggests that menu selection be augmented with command language capability.

Command language dialogue is user-initiated and can be accomplished with either function keys or software commands. This dialogue is appropriate only for trained, expert users. If it is applied inappropriately the result is a high information load for the user. Appropriate use of command language or use of both menu and command language dialogues make a powerful system with a great deal of user flexibility.

Further Research Needs

There is much left to be done in filling out design guides for visual display terminals. In general, the hardware or physical issues seem to be better understood than the software or informational dimensions. In the physical domain, there are needs for further investigation into such areas as image distortion and work surface light reflection. Given the current international concern, it is likely that reliable standards will be available in the near future.

It is important, however, not to restrict the future research to only the "easy" questions. At this point there is a serious need to begin a systematic development of coherent guidelines to guide informational design for screens. The issues are fuzzy and new; the medium of a computer allows more flexible as well as new strategies for design. It is important to explore the new capabilities and determine for whom and under what conditions they are appropriate. In particular, concern needs to be focused on the format and the cognitive fidelity of displays. Issues such as flexibility, power, and complexity need much more attention. Information load and display density are critical in determining user load, especially where overload may have catastrophic effects. The issue of the cognitive fidelity of displays is very new and requires a good deal of theoretical and empirical investigation. The computer allows designers to create displays which more adequately match or reinforce the user's model of the system or the user's current information needs. Matching displayed information to the user and his/her task is a logical but non-trivial use of the computer resources, one which begins to exploit the potential that the computer affords.

The Controller in the Loop

We now move out of the realm of the comfortably known into a realm where things get fuzzy, the role of the human in the controlling system. Figures 2a through 3 (consult Mitchell's paper in this proceedings, pp.260-265) illustrate the progression of man's relation to physical work. "In the beginning" work was done by the direct application of human energy, muscles, and perception. Soon, we removed ourselves from the work by the use of tools. With the Industrial Revolution, we began to use machines to do the work itself; we stepped back from the work to control the machine which performed the work. With the advent of computers and telecommunications, highly automated control systems have evolved. In these systems, the machines are directly controlled by a computer while the human directs the computer. At this stage, interaction by the human with the physical work may be entirely symbolic, through the mediation of a computational system.

This most recent development has occured within the last 30 years and, frankly, we still do not really know what it means. Different approaches to understanding have been advanced and are under continuing development

Much of this work is involved in the attempt to formulate and validate mathematical models of controller or supervisor performance. Older "classical" models of man at work, derived from bio-engineering, stimulus-response behavioral, and servomechanism notions, have been superceded by models based upon information processing, optimal control, and decision theories. An excellent introduction to such models is given by Sheridan and Ferrell (1974). Because highly automated systems tend to present the system controlled in symbolic form and receive instructions from the system supervisor similarly in symbolic form, the information processing models tend to dominate in this arena. Where the human controller is man-in-the-loop, as a coupling element in the control system itself, like a driver or a pilot, optimal control theoretic models have been applied with creditable success. Decision theoretic models are based in the task of choosing the appropriate response from a set of possible alternatives. These models are closely related to information processing models, but while the information processing model explicitly considers the information flow from man to controlled system and back, decision theoretic models focus on what the human controller does with the information received. This, in a design sense, can then drive the flow of data in the controlling system.

Figure 23 sketches an information processing model of the supervisory control system. Counterclockwise, a data display is generated by the system and is perceived by the human operator. The data perceived undergo mental procesing to determine an appropriate control action. The action is carried out by available controls, and direction and guidance are given to the system. A decision theoretic model might begin with mental process and progressively define the system in a clockwise fashion.

Figure 24 elaborates upon the mental processing notion. The perceived sensory inputs become available for processing after passing through a filter which is derived from a model of relevance held in long-term memory. From the filter, they pass into short-term memory where they are available for conscious processing. The data in short-term memory are used to used to select an action or strategy from long-term memory. These data may make their way into long-term memory, where they are used to update the long-term memory's model of relevance. This in turn updates the filter. A decision theoretic model might replace this model of mental process by an input-output mapping of states of the world to appropriate action.

These various models, optimal-control, information processing, and decision theoretic, have all been validated to some extent in experimental work in different applications. Each approach shows some explanatory power for particular tasks. Clearly, each approach grasps some part of the "truth" but we may be still at the stage of blind men touching the elephant in its different parts.

SUPERVISORY MODEL

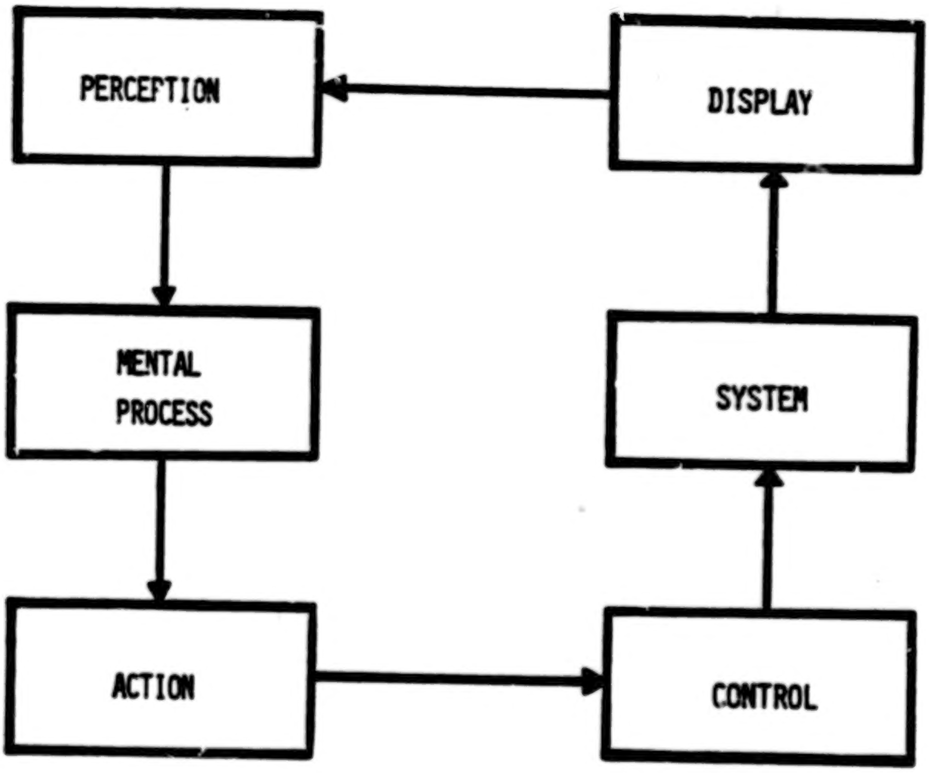

PERCEPTION
DISPLAY
MENTAL PROCESS
SYSTEM
ACTION
CONTROL

Figure 23

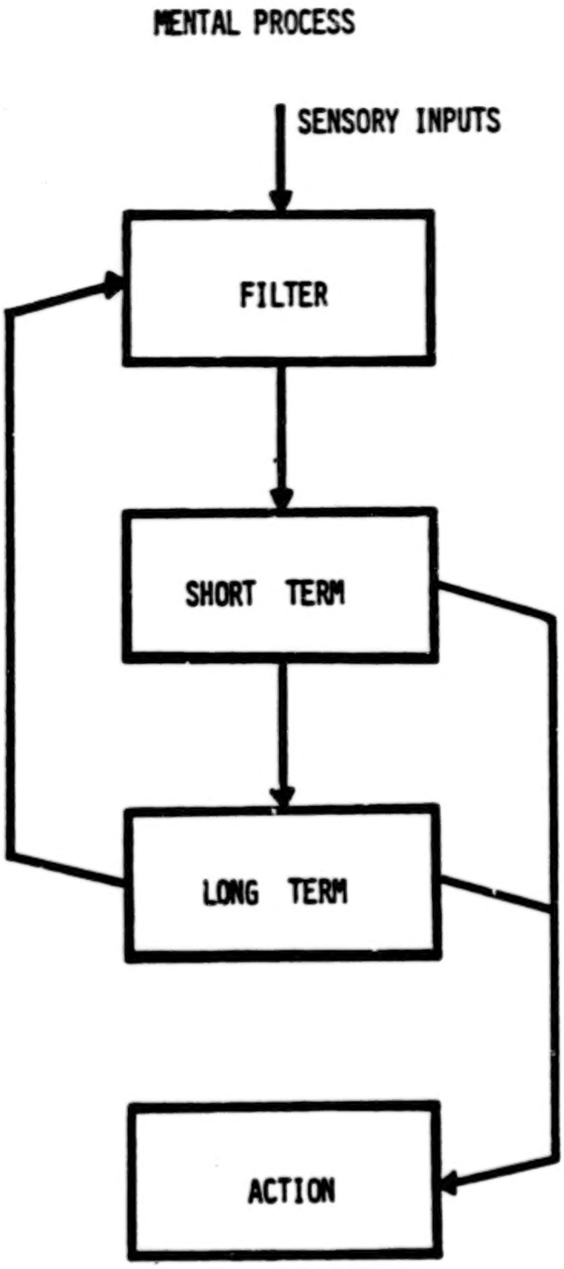

MENTAL PROCESS
SENSORY INPUTS
FILTER
SHORT TERM
LONG TERM
ACTION

Figure 24

As yet, none of these models gives us clearcut guidelines on the proper allocation of workload between man and machine in highly automated systems. There are, of course, intuitively obvious things which we can assert. For example, computers perform calculations much more rapidly and accurately than humans do; the machine should perform computational tasks. Similarly, machine memory is much more reliable than human memory; the machine should do remembering. Beyond these, when we ask which decisions should be made by which system component, answers become more hazy.

It can be asserted that humans make better decisions in ambiguous situations than computers do. Unfortunately, this assertion only drives us back one step, for then we must ask: does the machine or the human decide on the ambiguity of a situation?

Some researchers (Rouse,1981) suggest that the allocation of tasks between man and machine might best be dynamically determined. A fixed allocation of tasks, in a system running normally in steady state, may leave the operator with too little to do, resulting in boredom and a loss of vigilance. On the other hand, if a crisis erupts, the operator may then be overwhelmed by high-level tasks. The researchers suggest that the allocation of tasks might be made to maintain some given level of operator activity. When few "high-level" tasks need be done, "low-level" tasks are presented to the operator. When the qualitative level of activity increases, the computer releases the highest tasks to the human and resumes lower level tasks.

To this point, the terms "supervisor" and "controller" have been used interchangeably. Particularly in the context of allocation of tasks, these terms require some distinction. A "controller" is a person in the loop, a necessary link or coupling in the physical control of a system. A driver is a controller when he turns the steering wheel to cause a change in the direction of travel of the vehicle. When we speak of a "supervisor" to indicate that a computer has replaced the man in the loop, we mean that the computer worries about the actual activation of controls while the human directs the course of action.

Clearly, the two roles may be intermixed. When the driver/controller turns the steering wheel to change direction, the vehicle-supervisor has decided on a different tactical or strategic course for the car. The supervisory role is of a higher order than that of the controller, and it implies a measure of decision-making autonomy that the notion of controller does not include. (This is, of course, why control-theoretic models are better descriptions of controller behavior than they are of supervisory behavior.) In a highly automated environment, the human tends to the role of supervisor, guiding the system and determining goals and strategies while the computer can often best determine the best tactic or control action to fulfill the strategy.

At the root of much of our desire to understand fully the controller's or supervisor's role is the need to reduce error in performance of the role rather than to optimize performance per se. Error can creep in at any point in the information processing loop, from both mistakes of omission and of commission. Table 1, taken from NUREG/CR-1580, provides an illustrative list of sources of error in a control room.

Most systems can operate at a satisficing level of performance, somewhere short of optimal. The resources required to optimize system performance increase exponentially as higher levels of optimality are attempted. However, few systems are capable of surviving catastrophic human error such as driving a car into a brick wall at high speed. Thus we speak of maintaining system reliability, keeping the system in satisfactory operation within bounds of tolerance while avoiding disaster. As a rule, our machine systems are far more reliable than are our human systems. The human controller or supervisor is simultaneously the weakest and the strongest link in the chain. The design of human supervised control systems tries to compensate for the weaknesses and build upon the strengths of the human being.

Up to this point, our discussion has concerned the single controller or supervisor. In contemporary complex systems there may indeed be many such people interacting with a highly automated control system. This introduces a problem about which relatively little

DESIGN FEATURES INFLUENCING HUMAN ERRORS

1.0 CONTROL ERRORS

- 1.1 Inadvertent Actuation (Accidental Activation of a Control)
  - 1.1.1 Control location/arrangement
    - 1.1.1.1 Location with respect to the operator's body
    - 1.1.1.2 Location with respect to the operator's hand while controlling other controls
    - 1.1.1.3 Location with respect to other controls
  - 1.1.2 Control design
    - 1.1.2.1 No guards or barriers
    - 1.1.2.2 Too little force required to activate the control
    - 1.1.2.3 Type or motion required to activate makes accidental activation likely - e.g., toggle switch - up/down
  - 1.1.3 Control visibility
    - 1.1.3.1 Control is not easy to see and avoid
    - 1.1.3.2 View of control is obscured by other controls or operator's hand
- 1.2 Substitution Errors (Selection of the Wrong Control)
  - 1.2.1 Control location/arrangement
    - 1.2.1.1 Control located in a string of other controls of the same shape
    - 1.2.1.2 No consideration given to the sequence of control use
    - 1.2.1.3 No functional arrangement of controls
  - 1.2.2 Control design
    - 1.2.2.1 Control shape not differentiated from adjacent controls
    - 1.2.2.2 Control size not differentiated from adjacent controls
    - 1.2.2.3 Control color not differentiated from adjacent controls
    - 1.2.2.4 Control labelling/marking not readily distinguishable
    - 1.2.2.5 Control location not differentiated from other controls
    - 1.2.2.6 Difficult to distinguish pushbutton from legend light
  - 1.2.3 Control visibility
    - 1.2.3.1 Control not readily visible
    - 1.2.3.2 Line of sight to control is obscured
    - 1.2.3.3 Control label not readily readable
    - 1.2.3.4 Control label obscured by the control itself or by operator's hand
- 1.3 Activation Errors (Selecting Wrong Position on Right Control)
  - 1.3.1 Location/arrangement
    - 1.3.1.1 Control is located such that operator reach can result in mis-settings
    - 1.3.1.2 Control is located or oriented such that selection of some positions is difficult
  - 1.3.2 Control Design
    - 1.3.2.1 Direction of motion does not follow accepted stereotypes or conventions
    - 1.3.2.2 Direction of motion is not consistent for similar type controls
    - 1.3.2.3 Direction of motion is not labelled
    - 1.3.2.4 No feedback of control activation
    - 1.3.2.5 Control position arrangement is not consistent across different controls

Table 1 (Mallory et al.,1980)

        - 1.3.2.6 Control positions are not readily distinguishable
        - 1.3.2.7 The associated display is not located with the control
        - 1.3.2.8 The associated display motion does not follow convention
        - 1.3.2.9 The control permits selection of positions which are not used
        - 1.3.2.10 Labelling of control positions is difficult to read
        - 1.3.2.11 There is not sufficient spatial separation of different switch positions
    - 1.3.3 Control visibility
        - 1.3.3.1 Control position indications are obscured by the control itself or by the operator's hand
        - 1.3.3.2 The feedback cue to control activation is obscured
- 1.4 Temporal Errors (Taking Too Much Time to Locate, Acquire, and Activate a Control)
    - 1.4.1 Location/arrangement of controls
        - 1.4.1.1 Controls located out of reach of the operator
        - 1.4.1.2 Access to the control requires excessive travel on the part of the operator
        - 1.4.1.3 Accesss to the control requires special effort on the part of the operator
        - 1.4.1.4 The control is located in an array of identical controls
    - 1.4.2 Control design
        - 1.4.2.1 Force required to activate the control is excessive

- 2.0 DISPLAY ERRORS
- 2.1 Reading Errors
    - 2.1.1 Location/arrangement
        - 2.1.1.1 Display orientation to operator's line of sight is less than 45°
        - 2.1.1.2 Viewing distance makes reading difficult
        - 2.1.1.3 Display located above the eye height of a 5th percentile operator
        - 2.1.1.4 Display located such that operator's view is obscured
    - 2.1.2 Display design
        - 2.1.2.1 Displays difficult to read due to poor brightness contrast
        - 2.1.2.2 Display readability impaired by glare
        - 2.1.2.3 Scale increment size makes reading difficult
        - 2.1.2.4 Scale gradations not standard nor consistent
        - 2.1.2.5 Pointer parallax increases likelihood of reading errors
        - 2.1.2.6 Strip chart pens leak
        - 2.1.2.7 Strip charts use too porous paper
        - 2.1.2.8 Strip chart pens do not always contact paper
        - 2.1.2.9 Strip chart parameters require ranges different from those indicated
        - 2.1.2.10 Pullout strip charts obscure view of other displays
        - 2.1.2.11 Impact recorders difficult to read or to identify trends
        - 2.1.2.12 Conspicuity of pointers too low
- 2.2 Interpretation Errors
    - 2.2.1 Display design
        - 2.2.1.1 Displays do not indicate in-tolerance and out-of-tolerance areas
        - 2.2.1.2 Difficult to interpret trends

Table 1 contd.

    - 2.2.1.3 Process controllers display demand only, not actual value
    - 2.2.1.4 Required values not displayed on trend displays
    - 2.2.1.5 Patterns of lights are confusing
- 2.3 Display Substitution Errors
  - 2.3.1 Location/arrangement
    - 2.3.1.1 Display located in a string of identical displays
    - 2.3.1.2 Display located too close to adjacent displays
    - 2.3.1.3 Display not located in a string by sequence
    - 2.3.1.4 Displays not functionally grouped
    - 2.3.1.5 Display arrangement is illogical or inconsistent
    - 2.3.1.6 Display not located adjacent to its associated display
  - 2.3.2 Display design
    - 2.3.2.1 Display shape not differentiated from adjacent displays
    - 2.3.2.2 Display size not differentiated from adjacent displays
    - 2.3.2.3 Display color not differentiated from adjacent displays
    - 2.3.2.4 Display labelling not readily readable
  - 2.3.3 Display visibility
    - 2.3.3.1 Display not adequately illuminated
    - 2.3.3.2 Line of sight to the display is obstructed
- 2.4 Display Activation Errors
  - 2.4.1 Display design
    - 2.4.1.1 No light test capability
    - 2.4.1.2 No indicator lights are provided
    - 2.4.1.3 Direction of display motion not conventional or stereotypical
    - 2.4.1.4 It is possible to transpose legend light faces
    - 2.4.1.5 Trend recorder speed not controllable
    - 2.4.1.6 A failure to achieve required status is indicated by an extinguished light
    - 2.4.1.7 There is no standard procedure for checking failed lights
    - 2.4.1.8 A meter can fail leaving the pointer at mid-range
    - 2.4.1.9 Failure of a meter is not readily detectable
    - 2.4.1.10 Valve travel is indicated by extinguishment of open and closed lights
- 2.5 Display Temporal Errors
  - 2.5.1 Location/arrangement
    - 2.5.1.1 Display not located within visual access from viewing position
    - 2.5.1.2 Display is located in an array of identical displays
    - 2.5.1.3 Display located where field of view is obstructed
  - 2.5.2 Display design
    - 2.5.2.1 Displays not functionally grouped
    - 2.5.2.2 Displays not grouped by sequence of use
    - 2.5.2.3 Displays not clearly labelled
    - 2.5.2.4 Displays not clearly coded

3.0 ANNUNCIATOR ERRORS

- 3.1 Reading Errors
  - 3.1.1 Location/arrangement
    - 3.1.1.1 Annunciator legend cannot be read at viewing distance
    - 3.1.1.2 Annunciator legend cannot be read at viewing angle
  - 3.1.2 Annunciator design

Table 1 contd.

        - 3.1.2.1 Luminence level of red annunciator too low
        - 3.1.2.2 Annunciators have dyna-tape backfits which cannot be read when illuminated
        - 3.1.2.3 Annunciators have different type fonts
        - 3.1.2.4 Annunciator legends are too complex
- 3.2 Annunciator Activation Errors
    - 3.2.1 Annunciator design
        - 3.2.1.1 Annunciators not prioritized
        - 3.2.1.2 Annunciators not functionally grouped
        - 3.2.1.3 Annunciators not coded - as first out
        - 3.2.1.4 High annunciator nuisance rate reduces operator readiness
        - 3.2.1.5 Annunciator silence control is operated in a defeated mode
        - 3.2.1.6 Different flash rates or duty cycles indicate different annunciator status and the indicators are not readily distinguishable
        - 3.2.1.7 Auditory alarms are not coded by location
        - 3.2.1.8 No annunciator silence with visual display retention
        - 3.2.1.9 Until an alarm is cleared, a second alarm is inhibited
        - 3.2.1.10 Alarms are less than 20 dB above ambient noise levels
        - 3.2.1.11 Acknowledge control difficult to access
        - 3.2.1.12 No clear notification of alarm cleared

4.0 LABEL READING ERRORS

- 4.1 Readability
    - 4.1.1 Location/arrangement
        - 4.1.1.1 Labels not located consistently
        - 4.1.1.2 No labels provided
        - 4.1.1.3 No panel designators provided
        - 4.1.1.4 View of labels obscured
    - 4.1.2 Design
        - 4.1.2.1 Label font makes labels difficult to read
        - 4.1.2.2 Functions mislabelled
        - 4.1.2.3 Safety tags cover labels
        - 4.1.2.4 Labels have poor brightness contrast
        - 4.1.2.5 Labels are cluttered
        - 4.1.2.6 Labels have low contrast to the panel
        - 4.1.2.7 Labels are illegible
        - 4.1.2.8 Color not used consistently
        - 4.1.2.9 Inconsistent use of abbreviations
        - 4.1.2.10 Labels have small fonts
    - 4.1.3 Use of labels
        - 4.1.3.1 Too many operator added backfits used
        - 4.1.3.2 Backfits not consistent
        - 4.1.3.3 No demarcations grouping panel elements

5.0 PROCEDURE ERRORS

- 5.1 Access Errors
    - 5.1.1 Procedures location and arrangement
        - 5.1.1.1 Procedures are not located to be easily accessed
        - 5.1.1.2 Procedures are not arranged to be easily accessed
        - 5.1.1.3 Only are set of procedures provided in the CR
    - 5.1.2 Procedures indexing

Table 1 contd.

5.1.2.1 Procedures are not indexed for ease of access
5.1.2.2 Procedures are not tabbed for easy access
5.1.3 Procedures design
5.1.3.1 Procedure titles are not sufficiently discriminable
5.1.3.2 No guidelines are provided to enable operators to establish which procedures are applicable
5.1.3.3 No cross referencing of different procedures
5.1.3.4 Cross referencing sends the operator to some ancillary document

5.2 Reading Errors
5.2.1 Procedures design
5.2.1.1 Use of ambiguous language
5.2.1.2 Procedures text not clear and concise
5.2.1.3 Instruction too long
5.2.1.4 Use of overly precise control processor settings
5.2.1.5 Phrasing of instruction is ambiguous
5.2.1.6 Excessive length of instructional steps cause operators to skim rather than read these steps
5.2.1.7 Multiple steps are nested in one instructional statement
5.2.1.8 Caution and warning notes not sufficiently highlighted

5.3 Procedures Following Errors
5.3.1 Procedures design
5.3.1.1 Procedures are not complete - steps are missing
5.3.1.2 Procedural steps are out of order
5.3.1.3 Procedures do not inform the operator when to stop using the document
5.3.1.4 Emergency procedures do not indicate the feedback for the system which should cue the operator on what to do next, or even that he is on the right procedure
5.3.1.5 Procedure nomenclature different from labels and component designations
5.3.1.6 Information on component location and function left to operator's memory
5.3.1.7 Procedural steps in emergency procedures not structured to support diagnosis of problems
5.3.1.8 Charts, graphs and schematics and diagrams are not incorporated in the text
5.3.1.9 No indications are provided on system response to operator action
5.3.1.10 Procedures are not enumerable to a checklist format allowing operator checkoff of each step as completed
5.3.1.11 Too many steps of emergency procedures must be committed to memory
5.3.1.12 Arrangement of notes is confusing - not clear to which step the note applies
5.3.1.13 Inconsistent use of acronyms and action verbs

Table 1 contd.

is known from a human factors perspective: supervising the supervisors. How are multiple supervisors to be coordinated, integrated, and synchronized?

One obvious approach is the establishment of a hierarchy of supervisory roles, ultimately creating a pyramid in which one supervisor at the top directs all subordinate supervisors. Yet, in the real world, we observe the working together of autonomous controllers/supervisors or groups of controllers/supervisors who are linked by lateral relations and responsibilities but without explicit overarching control. In contrast to hierarchy, this situation is termed "heterarchy". To the surprise of many observers, hetararchic control systems persist in working in spite of conventional managerial and administrative wisdom. The relations between the POCs, MSOCC, NSCC, experimenters, ground stations, and other actors at GSFC, exemplifies heterarchy. Mutually negotiated SOPs and a general civility often appear to be the only binding forces among the myriad of activities involved in ground control of spacecraft from Goddard.

Conclusion

For our interim report, we have taken a bottom-up approach to what is known in human factors and their application. Starting with well-defined anthropometric measurements, we moved to a final discussion of supervising multiple-supervisor control systems. We have indicated that while much information is available and immediately applicable, much still needs to be done in the field in general and at GSFC in particular.

In NASA's Anthropometric Source Book(1978), the following guidance is given for the development and application of human factors in the manned space program:

1. Determine characteristics of the potential user population and select the appropriate anthropometric data base for analysis.
2. Establish what the equipment must do for the user—form, function, and interaction.
3. Select the principle interface of the user with the equipment.
4. Establish the anthropometric design values to be used in fabrication.
5. Design and evaluate a MOCKUP and revise design as necessary.

We suggest that this approach be adopted and adapted to the GSFC environment. Traditional engineering, even systems engineering, establishes what equipment must do, selects an interface(s) between the user and the equipment, and establishes design values. The manned-space-program approach expands these traditional tasks and greatly changes their emphasis.

The GSFC user and client populations are currently known only anecdotally. In real-time satellite control, many different user populations, from doctoral scientists to low-level technicians, are employed. To design effective and reliable systems, we need to know much more about the characteristics of these different groups. As we learn their salient characteristics, design can proceed to build upon specific strengths and to circumvent or minimize the potential harm of specific weaknesses. In other words, design values should flow from the human factors data, not simply from the specification sheets of hardware manufacturers.

The last step of the NASA manned-space program approach deserves special attention. The use of mock-ups, of experimentation, is intended not only to validate a specific design but to build up an empirical and practical body of knowledge. Too often we design and build hardware, test to determine that it functions, and install it without further ado or consideration of the human user. The point here goes far beyond simply "idiot-proofing" a piece of equipment to integrating the equipment with the physical, perceptual, mental, and motor capabilities of the user.

We know now that one outcome of our research will be the recommendation that GSFC establish an experimental facility in which a full-sized control room can be mocked up and real-time simulations be performed. This facility will also support measurement of user populations and research on VDT's and their use, particularly in the display of data, the use of interaction techniques, color, and other communications techniques.

The "well-known" human factors data need to be confirmed in the GSFC environment. But this is only a starting point. NASA systems for ground control of spacecraft are among the largest, most complex, and most sophisticated systems ever implemented by mankind. The full range of human factors questions introduced in this interim report are present in GSFC systems. This, of course, includes questions at the cutting edge of our experience and knowledge, the integration of single supervisors into healthy, efficient, highly automated systems and the integration of multiple system supervisors. Work advanced through a GSFC experimental and mock-up facility can greatly enhance our development of comprehensive theories and models of single and multiple control system supervisors that are practical and applicable to Goddard missions.

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SUMMARY OF WORKSHOP INTERACTION

Guidelines on Ergonomic Aspects of Control Rooms and Highly Automated Environments

There was surprise among the group participants that people objected to VDTs and computer-based tasks. Instead of building workstations to fit people, they asked, why not make adjustable workstation components? At this point, a participant commented on environmental ambience. He felt it was not cost effective to go "all out," especially if the workstation was used infrequently. Workshop moderators agreed with his point and suggested that a compromise should be reached between "all out" and "barely adequate". Participants were also interested in the length of time that individuals can comfortably view a CRT screen. They questioned how large the screen can,or should be.

These questions have no absolute answers at the present time but are representative of current research being conducted on video display terminals. Guidelines are available, however, for designing adjustable workstation equipment.

A CASE STUDY OF A SYSTEM ENGINEERED FOR CONTROL BY HUMANS

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A Case Study of a System Engineered for Control by Humans

Historically, NASA/GSFC unmanned spacecraft command and control, health and safety operations have been data and people intensive. The increase in spacecraft complexity, and the resulting increase in data requried to establish the spacecraft status, has made the traditional people-intensive command and control operation both costly and a higher risk. The increased use and capability of on board computers provides us with the opportunity to examine alternatives to the traditional concepts for real-time health and safety operations.

The pitfalls of the conventional contingency planning for health and safety are highlighted in Figure 1. The Solar Maximum Mission (SMM) contingency planning and operations provides one step in the evolution from this conventional people intensive health and safety operation, toward a "night watchman" mode of operations. The SMM spacecraft health and safety operations were budget constrained to the point that one week after launch one operator was responsible for the health and safety of the entire spacecraft. The spacecraft was a protoflight with brand new subsystem configurations, software and procedures. To manage the risks associated with this one man SMM health and safety operation, the real-time contingency planning and operations centered around unambiguously identifying a system level problem, and reactively safing components susceptible to unrecoverable damage. The methodology applied to both analyzing and implementing this approach of SMM is shown in steps I-V below:

STEP I. Identify spacecraft and experiment hardware damage susceptibility to unpredicted system level states.

i.e.
- Mispointing
- Unpredicted vehicle rates
- Computer failure
- Short on the power system

CONTINGENCY OPERATIONS

LARGE CONTINGENCY PLAN IS UNMANAGEABLE

- TRAINING VERSUS RETENTION
- PUTS UNFAIR RESPONSIBILITY ON THE HUMAN OPERATOR
- REQUIRES LARGE COMBINATION OF DATA AND DISPLAYS
- GENERALLY DOES NOT COVER OPERATOR ERRORS

MOST FAILURES ARE NOT COVERED IN THE CONTINGENCY PLAN

TIME AVAILABLE TO RECOGNIZE PROBLEM RANGES FROM LIMITED TO NONE

FIGURE 1 - TYPICAL CONTINGENCY OPERATIONS PROBLEMS

As a general rule all lower level failures or operator errors will manifest themselves into one or more system level anomalies.

STEP II. Identify the mimimum information and limit values required to unambiguously identify system level problems.

I.e. - P/Y & R position
Hardware/software
- S/C rates
Hardware/software
- S/C currents

These may be directly in the data stream or be computed prior to display.

STEP III. Identify, and allocate the functions and time response necessary to contain hardware damage (safe system).

I.e. - On-board command response
- control center command response time (prime and backup)

Allocation is based on operational on-board capability; time allowed from identification until damage irreversible.

Level of safing is dependent on recovery complexity.

I.e. - Turn off all instruments
- Leave computer running but disable command function

STEP IV. Establish operations policy, procedures and displays for health and safety monitoring, and contingency actions.

I.e. - Monitor these 20 parameters
- Get vehicle and instruments safe
- Issue procedure XYZ anytime mispointed

The operator should not be required to assume risk, he should be provided with the tools to recognize a problem and conservatively respond. Where one time science is involved "what if planning" and backup personnel should be provided.

STEP V. All other subsystem and benign system-level anomalies should be categorized and operator responsibilities defined.

i.e. - Unexpected configurations

- Thermal limits

The results of this analysis led to providing the SMM health and safety operations monitor, three levels of anomaly criticality, a clear policy, and approximately twenty-nine parameters, on two displays, within which he maintained spacecraft safety. The levels of SMM anomaly criticality and the SMM contingency operations policies are provided below.

Category I Contingency Actions

- Safe hardware
- Analyze problem
- Stabilize vehicle
- Notify in-depth analysis

Category II Contingency Actions

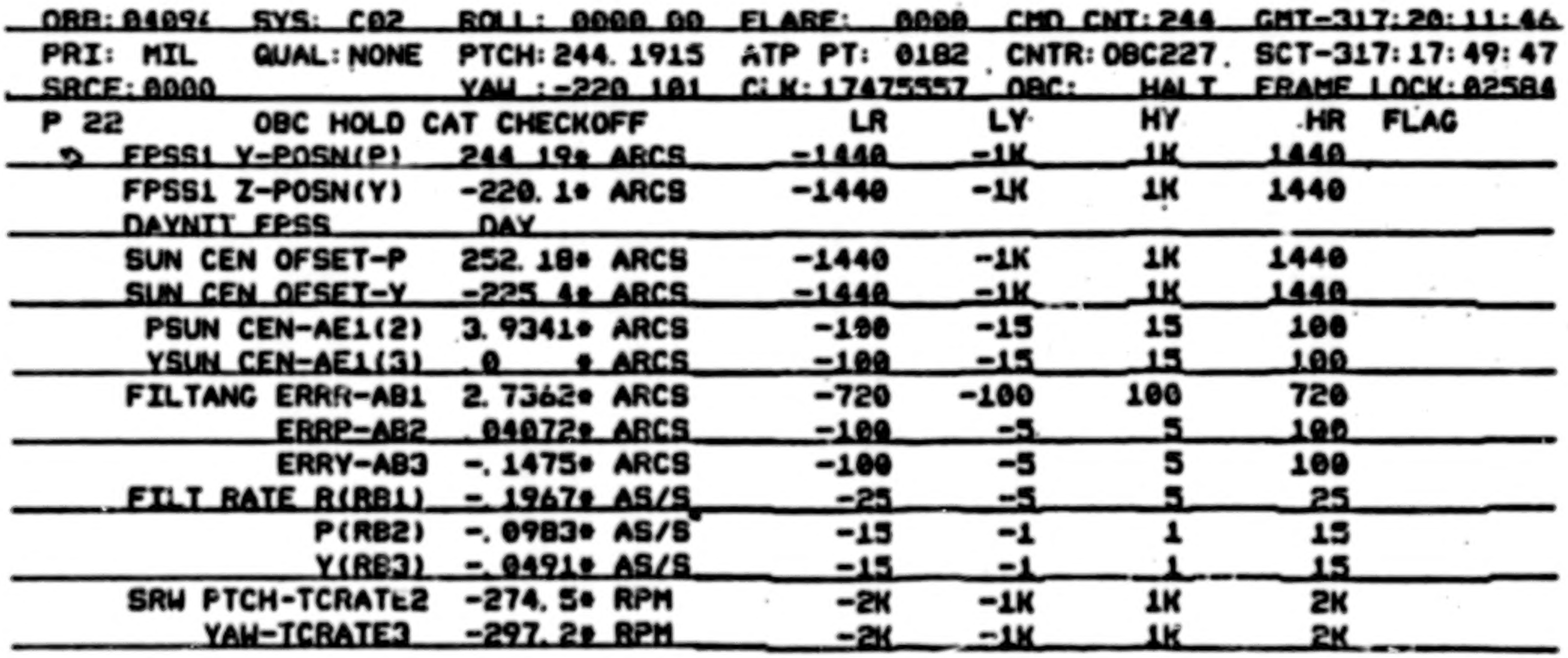
- Notify in-depth analysis
- Analyze problem
- Prepare to safe hardware

Category III Contingency Actions

- Notify in-depth analysis

The two displays provided to monitor the twenty-nine parameters are shown in Figures 2 and 3. The Flag column would provide the operator with an indication of a category 1, 2, or 3 severity, but more importantly instant cognition of a problem by simply noting an entry in the flag column. Simple unambiguous safing procedures which could be issued safely under any conditions were developed. A clear cut simple contingency plan shown in Figure 4 was the prime reference for operator safing response.

OBC/ACS CAT-1 CRT PAGE



```
ORB:04096  SYS: C02    ROLL: 0000.00  FLARE:   0000  CMD CNT:244   GMT-317:20:11:46
PRI: MIL   QUAL:NONE   PTCH:244.1915  ATP PT:  0182  CNTR:OBC227   SCT-317:17:49:47
SRCE:0000              YAW :-220.101  CLK:17475557   OBC:    HALT  FRAME LOCK:02584
P 22        OBC HOLD CAT CHECKOFF            LR      LY      HY       HR   FLAG
 ↩ FPSS1 Y-POSN(P)    244.19* ARCS        -1440     -1K      1K     1440
   FPSS1 Z-POSN(Y)   -220.1*  ARCS        -1440     -1K      1K     1440
   DAYNIT FPSS         DAY
   SUN CEN OFSET-P    252.18* ARCS        -1440     -1K      1K     1440
   SUN CEN OFSET-Y   -225.4*  ARCS        -1440     -1K      1K     1440
    PSUN CEN-AE1(2)  3.9341*  ARCS         -100     -15      15      100
    YSUN CEN-AE1(3)   .0    * ARCS         -100     -15      15      100
   FILTANG ERRR-AB1  2.7362*  ARCS         -720    -100     100      720
           ERRP-AB2   .04072* ARCS         -100      -5       5      100
           ERRY-AB3  -.1475*  ARCS         -100      -5       5      100
   FILT RATE R(RB1)  -.1967*  AS/S          -25      -5       5       25
             P(RB2)  -.0983*  AS/S          -15      -1       1       15
             Y(RB3)  -.0491*  AS/S          -15      -1       1       15
   SRW PTCH-TCRATE2  -274.5*  RPM           -2K     -1K      1K       2K
         YAW-TCRATE3 -297.2*  RPM           -2K     -1K      1K       2K
```

FIGURE 2 - SMM CATEGORY 1 REAL-TIME CONTINGENCY MONITOR (1 of 2)

POWER CAT-1 CRT PAGE

```
ORB:04094  SYS: C02   ROLL: 0000.00  FLARE:  0000  CMD CNT:244   GMT-317:20:11:28
PRI: MIL   QUAL:NONE  PTCH:244.1915  ATP PT: 0102  CNTR:0BC227   SCT-317:17:49:47
SRCE:0000             YAW : -220.101 CLK:17475557  OBC:    HALT  FRAME LOCK:02584
P 21          POWER CAT CHECKOFF         **LR   **LY   **HY*   -*HR        FLAG
     FSSS / SUN PRES    DAY
     LD BUB VOLTAGE     31.519* VDC      25.1   25.6   32.1    32.4
     BATT VOLTAGE 1     31.359* VDC      25.1   25.6   32.1    32.4
     BATT VOLTAGE 2     31.359* VDC      25.1   25.6   32.1    32.4
     BATT VOLTAGE 3     31.359* VDC      25.1   25.6   32.1    32.4
     BATT HIGH CURR 1   .79998* AMPS      -13    -10     25      31
     BATT HIGH CURR 2   .79998* AMPS      -13    -10     25      31
     BATT HIGH CURR 3   .79998* AMPS      -13    -10     25      31
     QUIET LD BUS CUR   4.7999* AMPS      0.3    3.0    8.7      10
     PULSE LD BUS CUR   .19123* AMPS    -----   ----      2       3
     HTR BUS CURRENT    1.1952* AMPS    -----   ----    8.7      10
     SCCU/MFS CURRENT   4.8799* AMPS      1.2    1.4    6.4     8.4
     MACS CURRENT       3.8099* AMPS      2.3    3.4    8.5      12
     CDH CURRENT        3.6799* AMPS        2    2.5      6       8
     TOTAL LD BUS CUR   18.235* AMPS      5.0    9.0     29      34
```

FIGURE 3 - SMM CATEGORY 1 REAL-TIME CONTINGENCY MONITOR (2 of 2)

MAJOR CAT-1 PROBLEMS (NORMAL OPS.)

PROBLEM	DEGREE	IMMEDIATE ACTION	USING	COMMENTS
OBC CRASHED	SAFE HOLD A PROPERLY HOLDING OR NULLING.	1. SAFE ALL INSTRUMENTS.	C146	
	SAFE HOLD A NOT WORKING PROPERLY.	1. SAFE ALL INSTRUMENTS. 2. SWITCH TO SAFEHOLD B.	C146 A204	PROBABLE FAILURE OF PRIME HARDWARE.
	SAFE HOLD B NOT WORKING EITHER.	1. CHECK TORQUERS, RATS, WHEELS/DRIVERS.		PROBABLE FAILURE OF PRIME ACTUATOR.
EXCESSIVE MISPOINTING OBC STILL RUNNING	ON MAIN BODY OF SUN.	1. CANCEL SLEWS.	A356 B572	MAY BE BAD SLEW TABLE. CANCEL SFT.
	NEAR LIMB, OR JUST OFF SUN. (±1500 SEC).	1. SAFE C/P & UVSP. 2. CANCEL SLEWS.	X010 A356 A303	NEAR DANGER ZONES FOR C/P AND UVSP.
	FAR OFF SUN.	1. SAFE C/P & UVSP. (SUN PRESENCE) < 2° (SUN PRESENCE) > 2° (NO SUN PRESENCE)	X010 A336 A338 A356	THERMAL RESTRICTIONS.
EXCESSIVE DRIFT OBC STILL RUNNING	HIGH P OR Y DRIFT.	1. SAFE C/P & UVSP. 2. P,Y NULL-AX.	X010 A303 B767	
	PURE ROLL DRIFT.	TAKE NO IMMEDIATE ACTION.	----	NOT CAT-1 SEVERITY.
EXCESSIVE WHEEL SPEED	WITH OBC STILL RUNNING. FOR SAFEHOLD CASE, SEE "OBC CRASHED" ABOVE.	1. SAFE ALL INSTRUMENTS. 2. HI-RATE MAG DETUMBLE TO CSS NULL. 3. TAKE NO OTHER IMMEDIATE ACTION.	C146 CONT. A206	OBC COULD CRASH. RE-ACQUIRE SUN, UNSAT WHEELS. NOT CAT-1 FOR WHEEL ITSELF.
EXCESSIVE DRAIN INTO BATTERY	1 OR 2 BATTERIES.	1. ISOLATE FAILED BATTERY(S). 2. REDUCE EXPERIMENT POWER.	LOOK UP GRP. C146	ISOLATE FAILURE, REDUCE POWER, ANALYZE CAPABILITY.

*B453 CANCELS BUFFER AREA FOR TABLE 55.

FIGURE 4 - REAL-TIME OPERATIONS CONTINGENCY PLAN

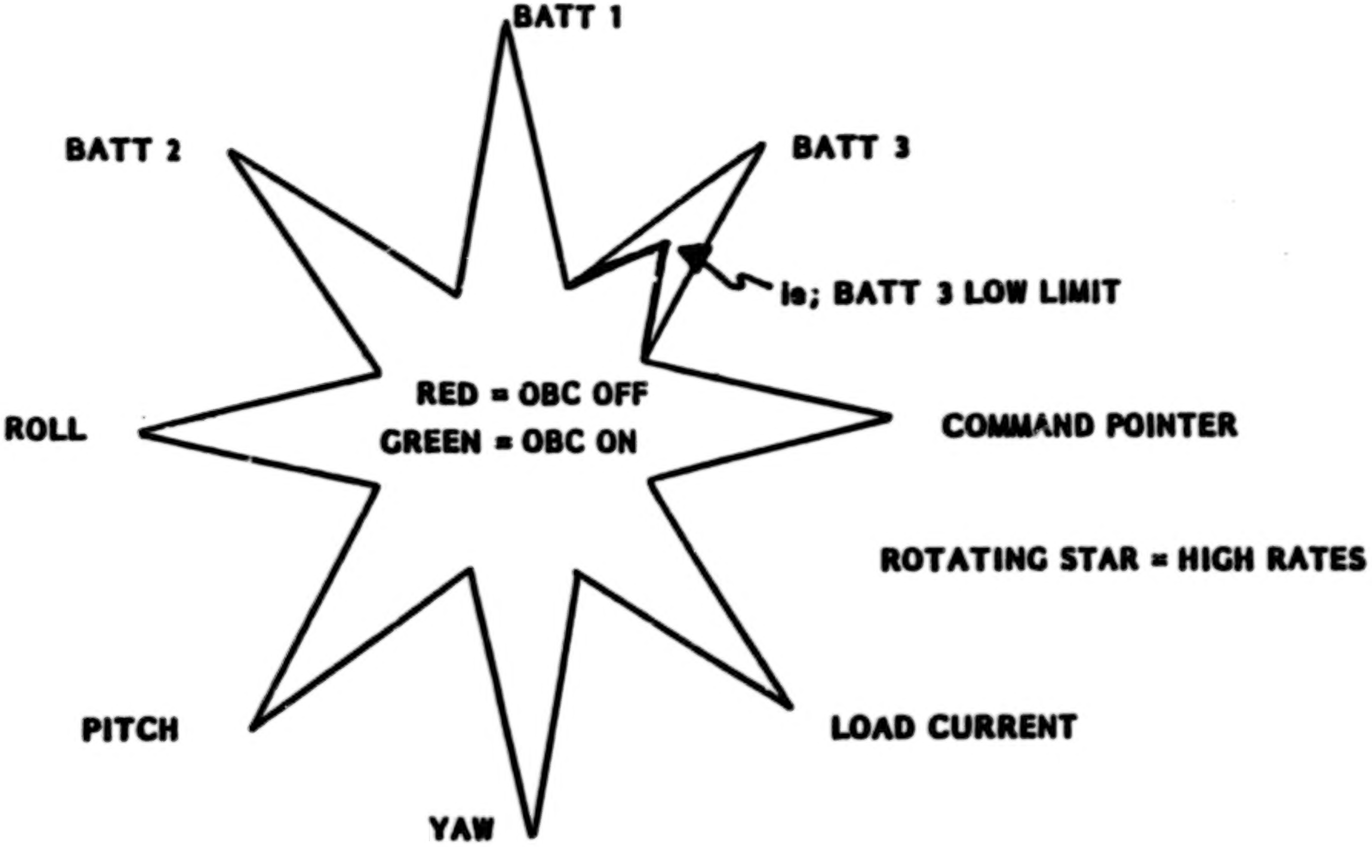
The second result from the contingency analyses was the identification of those safing actions that were so time critical, they must be initiated by the on board computer. These were incorporated into the software applications processors.

The successful results of the SMM contingency planning and operations implementation provides the basis for a further simplification of spacecraft health and safety--the "watchman concept." The basic signal to the SMM monitor that a problem existed was his observation of a flag in the last column of the two displays shown in Figures 2 and 3. One could easily see extending this concept to elimination of everything on the display except the flag column.

The experience gained on SMM, coupled with increasing operations costs, increased use of flight computers, TDRSS, and ground system graphics provide the opportunity to re-evaluate health and safety operations. The historical evolution of the personnel assigned to monitoring spacecraft health and safety presents another consideration. Traditionally the "experts" at launch are off to their next project and are replaced by pure monitors by six months after launch. The personnel exposed to contingency training and familiar with the documentation are generally no longer around.

Cost, technology and personnel considerations lead to a suggestion that future operations be system engineered to implement a different real-time health and safety operational philosophy, the "watchman concept." The essence of this concept is to provide information, that identifies problems, not data, and on board safing to protect hardware and contain the problem to the failed component.

Systems engineering for the human function in health and safety should consider the operator likely to be in place for the routines operation. We need to provide both an operator friendly approach to contingency design as well as the information in a form that the less experienced operator can readily recognize and react to system problems. The star icon in Figure 5 illustrates one approach to displaying


BATT 1
BATT 2
BATT 3
Is; BATT 3 LOW LIMIT
RED = OBC OFF
GREEN = OBC ON
ROLL
COMMAND POINTER
ROTATING STAR = HIGH RATES
PITCH
LOAD CURRENT
YAW

SHAPE,COLOR AND ICON MOTION CAN READILY ALERT THE TRAINED OR LAYMAN TO SYSTEM PROBLEMS

FIGURE 5 - THE WATCHMAN DISPLAY CONCEPT

BEST DOCUMENT AVAILABLE

information which both could provide "the watchman" type operator with a clear indication of a problem, and the experienced operator with the same indication. It also however provides a second level of information detail as to the nature of the problem. Either ground or on-board automated responses could take the initial safing step. Any change in symmetry, color or stability of the star would readily be detected. The sample points shown in fact represent those category 1 flags shown in the SMM displays of Figures 1 and 2.

Once the concept of information display is accepted and readily recognizable forms of display are developed, the real-time health and safety monitoring for many spacecraft simultaneously by a "watchman" could be a realizable operations goal for NASA. As with today's operations the watchman would call "the expert" as soon as he detects an anomaly.

The idea can be extended throughout operations. The center director could have a bank of screens or even a composite icon, which at a glance gives him operational spacecraft status. Remote experimenters could be given status information in the same fashion. Sometime in the future, night and weekend health and safety operations monitoring may even be able to be added to the security guards checklist.

CONCEPTUAL MODELS OF INFORMATION PROCESSING

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CONCEPTUAL MODELS OF INFORMATION PROCESSING

Introduction

Human information processing has been studied and investigated extensively within the field of experimental psychology, particularly in the areas of human memory and cognitive psychology. Understanding the conceptual bases of human information processing is important for any student of human behavior. It is especially necessary for those who utilize humans as system components. Kantowitz (1982) argues persuasively for a human factors approach to human information processing that would integrate theoretical research results into applied settings. The benefits of this approach include a valid and reliable foundation for specific system design guidelines and a more effective human component in a system, with greater productivity and less margin for error. This paper will focus on the conceptual information processing issues and integrate applied factors where appropriate. As numerous books have been published concerning human information processing, an attempt has been made to provide an overview of the major issues.

Definitions

Human information processing can be defined as an active cognitive process that is analogous to a system. It is the flow and transformation of information within a human (Kantowitz, 1982). The human is viewed as an active information seeker who is constantly receiving, processing, and acting upon the surrounding environmental stimuli. Human information processing models are conceptual representations of cognitive behaviors. They attempt to delineate what cognitive process occurs and when and how these activities interact. Models of information processing are useful in representing the different theoretical positions and in attempting to define the limits and capabilities of human memory.

To place limits on the human's information processing abilities, an objective measure of information must be used. Psychologists measure information in bits (the term is a shortened version of binary units); a bit is the amount of information available to the human when one of two likely alternatives is chosen. There is an exponential relationship between bits and amount of information. It is expressed mathematically as:

$$H = \text{Log}_2 K$$

where K is the number of equal alternatives and probabilities and H is equal to the amount of information received. If the human is presented with eight equally likely alternatives a choice will yield three bits of information; sixteen alternatives, four bits, etc. The relationship is also expressed as the number of bits increasing as the amount of uncertainty decreases. It is estimated that the human memory can store between 100 million and 1 million billion bits of information (McCormick, 1976), a greater storage than any existing computer storage. Figure 1 illustrates the bits of information a human receives when processing familiar items like digits and letters. The system designer would seek to measure information objectively in bits, to provide a criterion for applied issues. When the amount of information received is considered in conjunction with human processing capabilities, design issues such as number of displays for one task, number of coded colors on a command panel, or number of auditory codes are affected.

Human vs. Computer Information Processing

Many human information processing models are analogous to computer information processing systems. The underlying flow or structure appears to be the same. Figure 2 represents a simplified flow diagram that applies to both human and computer information processing systems. Humans input data from the senses while the comp ystem receives it from interactive devices. Both systems recognize, attend to, process and store information, and both output some kind of information or action. The data output often becomes the data input for the next thought or task thus

ITEM	BITS OF INFORMATION
BINARY DIGIT	1.00
DECIMAL DIGIT	3.32
LETTERS	4.70
ALPHA-NUMERICS	5.17

FIGURE 1 - MARTIN, 1973, P. 337

FLOW DIAGRAM OF HUMAN/COMPUTER INFORMATION PROCESSING SYSTEM

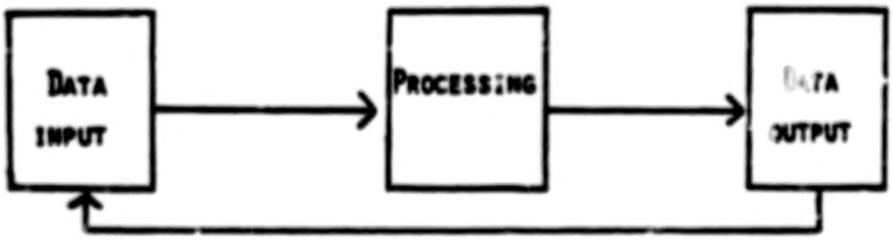
DATA INPUT
PROCESSING
DATA OUTPUT

FIGURE 2

emphasizing the continuous loop process in both human and computer information processing.

When a human is placed within a computer system, it is important for the designer to recognize that the human processing system interfaces directly with the computer processing system. Figure 3 is a simplified flow diagram illustrating this interface. The output of one system provides input for the other, and to ensure optimal operations the computer processing loop should interface smoothly with the human processing loop (i.e. overload or ambiguous messages should be avoided).

Short Term Memory/Long Term Memory Store Model

The traditional conceptual information processing model is the short term memory (STM)/long term memory (LTM) store model. Proponents of this model conceptualize information processing as processes occurring in three distinct memory stores: sensory, short term memory, and long term memory. The stores are not physical entities existing in the human's mind, but rather, useful theoretical structures delineating the ongoing cognitive activities. A flow chart representation of this model can be found in Figure 4.

The initial memory store for information processing is the sensory store. It is a perceptual store thought to have two major sensory channels and to operate on a subconscious level. The visual or iconic store receives information from the eye while the auditory or echoic store receives through the ear. Sperling (1960) and Darwin, Turvey and Crowder (1972) offer some experimental evidence for the existence and differentiation of these two sensory stores. Both are considered brief repositories for perceptual information capable of holding up to four or five items (known as the span of apprehension) for 10 to 200 milliseconds (Loftus & Loftus, 1976).

It is an accepted fact that a large portion of the visual and auditory information in an environment is perceived by the human. The cocktail party phenomenon illustrates this. When in a situation where several conversations are occurring at once, the human is

FLOW DIAGRAM OF HUMAN PROCESSING/COMPUTER PROCESSING LOOP

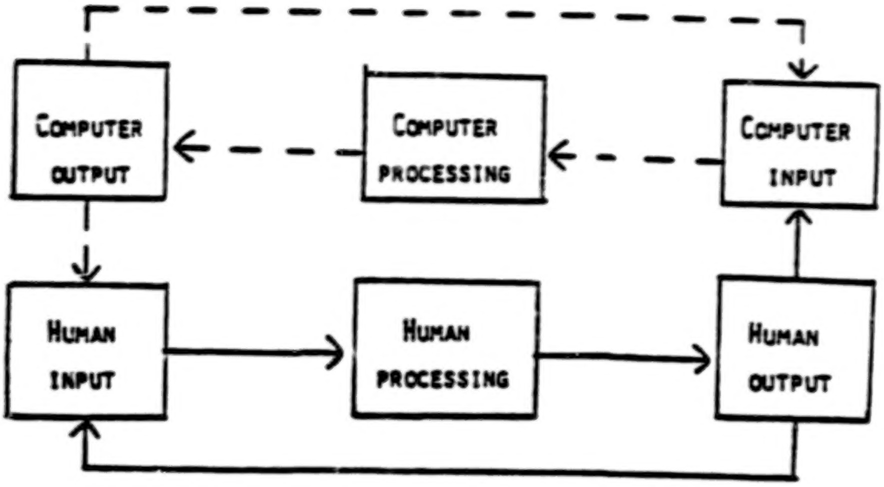
COMPUTER OUTPUT
COMPUTER PROCESSING
COMPUTER INPUT
HUMAN INPUT
HUMAN PROCESSING
HUMAN OUTPUT

FIGURE 3

SHORT TERM STORE/LONG TERM STORE MODEL

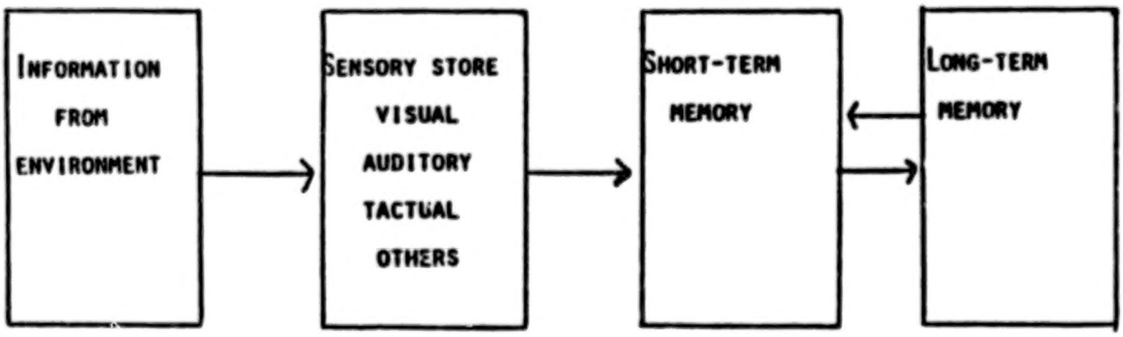
INFORMATION FROM ENVIRONMENT
SENSORY STORE
VISUAL
AUDITORY
TACTUAL
OTHERS
SHORT-TERM MEMORY
LONG-TERM MEMORY

FIGURE 4 - BRANSFORD, 1979, P. 37

able to perceive many of them. However, the raw sensory information is useless until some meaning is attached to it. The processes of pattern recognition and attention accomplish this and in doing so, transfer the selected information into the next store — short term memory. Otherwise, the sensory store has a very rapid decay rate. The human attends to one cocktail party conversation and excludes all of the surrounding perceptual noise from consciousness; the perceptual stimuli from lighting, music and other voices decay.

The second phase of the STM/LTM model is the short term memory store, having limited capacity and containing information being currently processed by the human. Experimental research using free recall paradigms and resulting in serial position curve evidence (subjects are given a list of nonsense syllables to learn and when asked to recall them, remember more items from the beginning and end of the list, rather than in the middle) supports the existence of a short term memory along with a long term memory (Loftus & Loftus, 1976). The short term store receives information from both sensory and long term stores (Figure 4) and is capable of holding information up to 15 seconds. However, it is a transient store and its contents continuously change unless rehearsed. Rehearsal, either verbal or mental, allows the human to hold information in short term store for longer periods of time (e.g., repeating a phone number as you walk from the directory to the phone), or to transfer it to long term store (e.g., individual's personal phone numbers become ingrained after repeating them often enough). Miller (1956), determined short term store capacity to be seven plus or minus two (7 ± 2) items. The information content of the short term store is independent of item number because it is possible to increase it through the process of chunking. Chunking is a subjective organization that incorporates information from several items into one chunk (e.g., when trying to recall a list of 12 letters, chunking them into four familiar acronyms, IBM-FBI-PHD-TWA, facilitates retention (ANACAPA Sciences, Inc., 1981)). The information content per chunk can be objectively measured by determining the number of bits needed to encode or understand the chunk. When incoming information exceeds the human's short term store capacity, a breakdown in the ability to learn and understand occurs. Chunking information will help avoid this and give the person a greater available store, increasing the capacity to process information. There are individual differences in the short term memory store capacity (i.e., some are able to incorporate greater amounts of information into one chunk than others), but the number of items remains at 7 ± 2.

The rehearsal and organization of information transfers it to the final phase of the STM/LTM processing model — long term memory store. Long term store is a permanent memory holding all sensory and semantic information necessary for thinking. It is conventional memory that holds all the human's knowledge of the world. Information is encoded and held here and can be retrieved through the processes of recognition and recall. The strength of a memory "trace" and the associative pathways of memory facilitate these retrieval processes, respectively (Bransford, 1979). Decay from long term store, or forgetting, takes place due to interference and retrieval failure. Two types of interference are suggested: proactive, when information processed before receiving an item to remember affects the recall of that item, and retroactive, when information processed after receiving an item to remember affects its recall.

Semantic/Episodic Long Term Memory Model

A body of research suggests two types of long term memory (Tulving, 1972). Both types are permanent memory stores, but they differ in content. Like the STM/LTM model, this model makes a conceptual, rather than physical, distinction between stores. Episodic long term memory is context specific and stores temporally coded information. How and when things occur, as they affect the individual, make up the content of episodic memory. The information within this store is considered autobiographical and changes quickly and continuously (Klatzky, 1980). Episodic long term store is quite susceptible to forgetting because the very act of retrieving or remembering information becomes a temporal event to be stored. This, plus the constant flow of new events as they are experienced and stored by the human, leads to a greater likelihood of forgetting.

Semantic long term store, the other memory store proposed by this model, is not as susceptible to forgetting and is not context specific. Semantic memory contains all the human's general knowledge of concepts, principles, and meanings. It holds information that is independent of time and place of occurrence, e.g., spelling rules, multiplication tables, and does not change very rapidly. The act of retrieval does not affect the store; and, as it is highly organized, retrieval is not random (Klatzky, 1980).

The semantic/episodic long term memory model is partly an extension of the STM/LTM model. However, the STM/LTM conceptual model of information processing remains a dominant theory representing human information processing.

Design Implications of the STM/LTM Model

Two dimensions are used by humans to discriminate information within the sensory store. One is an absolute discrimination, the other, relative discrimination. When humans are presented with a single stimulus and have to discriminate it from all others they must go to long term memory store to do so. The human information capacity is limited for making these absolute discriminations, and Figure 5 shows the capacity range for this kind of activity. As illustrated, the capacity for making absolute discriminations is 7 ± 2 items. However, when humans are presented with two stimuli at once and must make a relative discrimination between the two, their capacity for making discriminations is greatly increased. This implies that relative discriminations are much more efficient for human information processing and should be relied upon for quicker and less error prone judgements. Relative discriminations greatly increase the short term store capacity.

Range of absolute discriminations

STIMULUS DIMENSIONS	AVERAGE DISCRIMINATIONS
PURE TONES	5
LOUDNESS	5
BRIGHTNESS	5
SIZE OF VIEWED OBJECTS	7
COLORS	9

Figure 5 - ANACAPA Sciences, Inc., 1981, Session 13

Type of Item	Memory Span
Digits	8
Colors	7
Letters	6
Words	5
Shapes	5

Figure 6 - ANACAPA Sciences, Inc., 1981, Session 13

As stated earlier, the short term store capacity is limited. Figure 6 lists five different types of items humans process and the corresponding short term memory span of each. Memory span is defined as the longest list of items that can be recalled without error immediately after presentation (ANACAPA Sciences, Inc., 1981). Memory span differs according to item type but hovers around 7 ± 2 items. For humans to process quickly and effectively the information these example items represent, the capacities for each should not be exceeded.

One of the main contributions a human makes to a system is the ability to recognize patterns. Taking small chunks of information and encoding them into larger chunks is a major human information processing skill. This ability can be highly utilized through the graphic representation of information. Graphic displays encode large amounts of information into one chunk or item, increasing the short term memory capacity greatly and making the human a more effective information processor.

Strategies for Information Processing Model

Some experimental research criticizes the STM/LTM model as being too structured when considering the cognitive activities involved in information processing (Moray, 1978; Underwood, 1978a). The "flow chart" approach of the STM/LTM model does not consider the individual variability of processing sequences; it implies a structurally limited response process. The strategies for information processing model accounts for these variable individual processing sequences (i.e., strategies) within the structured limitations suggested by the STM/LTM model. Human information processing is thus viewed as an individualistic and dynamic activity due to the wide range of available strategies.

Moray (1978) defines a strategy as the "subtle striving of a rather rational agent in a fairly orderly universe, implying the goal-directed, purposeful use of resources" (p. 302). Strategies manipulate incoming information dependent upon the individual's goals and expectations. The same stimulus offers different information to different individuals. One person may process information using the sentence structure of some text while another may use the spatial location of items within the same text. Subjective organizations of information (i.e., chunking) are considered strategies.

Proponents of this conceptual model stress the assumption that strategies are individually determined, yet work within cognitive structural limits. This assumption precedes others; the limits of one cognitive structure necessarily affect processing in other structures, past success with one strategy leads to its recurrent use, as well as lack of awareness for alternative strategies, and experimental assessment of strategies is inherently difficult.

Strategies for human information processing are important elements of systems that involve ongoing human control. The operators of systems providing status information will develop optimal monitoring strategies that can be positive or negative depending on the situation (Moray, 1978). While they may not be aware they are using strategies, their behavior reflects it. Strategy use by operators in complex systems is somewhat beyond the scope of this paper; the reader is directed to Moray (1978) and Underwood (1978b) for an in-depth treatment of the topic.

The use of strategies for any human behavior is presently being researched by experimental psychologists. Strategies for information processing is the current model under investigation; therefore, all experimental results are not in. As it is, the model leaves several unanswered questions. However, it is perhaps the most inclusive model of information processing available and an exciting alternative to the STM/LTM model.

Levels of Processing Model

The fourth conceptual information processing model for review is the levels of processing model (Bransford, 1979; Craik & Lockhart, 1972). It is similar to the STM/LTM model, proposing three stages of memory called levels. It differs from the

STM/LTM model by defining the levels as processes rather than structured stages. The model assumes that information is processed by the human at different levels varying in depth. The first level is the physical or perceptual level where processing occurs in terms of the physical appearance of stimuli. The next level is acoustic where processing takes place in terms of how stimulus information sounds. The semantic level is last, and processing here is in accordance with stimuli meaning. It is suggested that these processing levels are ordered by depth, with physical attributes being processed at the most superficial level and semantic attributes at the deepest level. Information need not be processed at one level before going to the next; rather any of the three can be directly accessed in any order. The levels are ordered by depth only. The major assumption this model makes is that deeper processing leads to better memory. Briefly, supporting theory states that processing of information leaves traces upon memory; the deeper the processing the deeper the traces, thus leading to better memory (Bransford, 1979).

There are criticisms of this model. The assumption that deeper processing leads to better memory must be qualified by the type of experimental task used to measure retention. There is no objective measure of depth in this model. The experimental results show only that semantic processing is more effective for retention tasks than physical processing, not that one level is deeper and thus more effective for information processing. Without an objective measure of depth, the major assumption of the model can be challenged. The model does have preliminary support, and it provides another useful conceptual alternative.

Serial vs. Parallel Processing

The last conceptual information processing model, to be addressed briefly, is a dichotomous model focusing on pattern recognition. Items of information are processed or recognized one at a time sequentially in serial processing. In parallel processing several information items are processed simultaneously. Experimental evidence for this model supports the existence of both processing types, rather than one as opposed to the other (Klatzky, 1980). Also, both appear to operate within all information processing mechanisms, especially the sensory store.

Although both serial and parallel processing are thought to occur in humans, most display designs are based on the assumption that humans are parallel processors. Parallel processing best detects threshold changes; but, where specific event changes need to be detected, serial processing is better. Real-time control situations call for parallel processing of information; however, there are limits to the parallel processing capabilities. When information is presented too rapidly human performance suffers. Speed stress taxes human capacities, and performance on time shared tasks suffers (McCormick, 1976). Therefore, display designers are cautioned against presenting information at a rate greater than the human's parallel processing capabilities.

Summary and Further Design Implications

There are other conceptual information processing models, both similar and dissimilar to those outlined above. The five addressed here have one common premise: human information processing is a system. When the human component is interfaced with a machine system, designers must consider human information processing system limits and capabilities. Figure 7 provides a flow chart illustrating the human information processing/machine system interface. The productivity of the entire system will be increased by this consideration. It is a simple proposal; but, as Kantowitz (1982) suggests, it is not always implemented due to the philosophical differences between theoretical and applied scientists. Both basic and applied research can benefit one another, resulting in design suggestions for better human-machine interfaces.

A great deal of experimental research has used human reaction time to a stimulus event as a dependent variable, providing several specific results. The more cognitive

FLOW CHART OF INFORMATION PROCESSING
WITHIN A SYSTEM

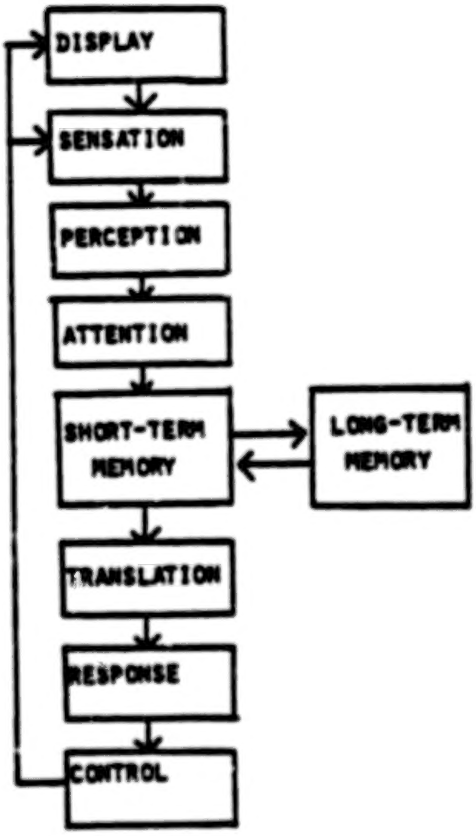
DISPLAY
SENSATION
PERCEPTION
ATTENTION
SHORT-TERM MEMORY
LONG-TERM MEMORY
TRANSLATION
RESPONSE
CONTROL

Figure 7 - Durrett & Stimmel, 1982, p. 399

activity a task involves, the longer it takes humans to process and react to the information (Van Cott & Warrick, 1972), implying a decrease in cognitive task load to achieve rapid response rates. Movements of the eye, finger, or tongue give the fastest reaction times, while head and foot movements take longer (Pew, 1971). Reaction time is also affected by the ease with which one signal is detected from others. For example, Pew (1971) reports that humans respond much more quickly to a red signal when it is chosen from a red, green and yellow array, than when it is chosen from a red, red-orange and orange array. Human reaction time is fastest and error rates lowest when there is direct stimulus-response compatibility (ANACAPA Sciences, Inc., 1981); adherence to population stereotypes helps achieve this. Labelling equipment numerically in one situation and alphabetically in another increases the translation steps necessary for the human, reduces the stimulus-response compatibility, and increases reaction time. Enough practice with equipment that goes against population stereotypes eventually offsets the ill effects of incompatibilities for normal situations. However, if humans are operating in overload or stress conditions, they have a greater likelihood for error when using incompatible designs; the practice effect washes out.

Designers should consider several criteria for information presentation as suggested by ANACAPA Sciences, Inc. (1981). They are:

- detectability
- discriminability
- compatibility
- redundancy
- meaning
- standardization

Consideration of each criteron will lead to more effective human-machine interfaces.

Research shows that use of different sensory channels affects information processing (McCormick, 1976; Van Cott & Warrick, 1972). Auditory stimuli capture the human's attention better than other sensory channel stimuli, suggesting their use for warning or special events. The use of added channels to provide redundant information increases the probability of reception; but to do so the information must be identical and presented simultaneously. The number of channel competing sources should be minimized. The sensory channel capacity is limited, and Figures 8 and 9 provide measurements of those capacities for unidimensional and multidimensional stimuli, respectively.

One effect of stress on the human is a narrowing of attention. In emergency or time critical situations information overload should be avoided; displays and tasks for those situations should be designed as simply as possible. It was suggested above that the presentation rate for effective information processing is limited. Van Cott and Warrick (1972) report that humans cope with excessive information presentation rates by using one or several counter-productive measures. They will fail to respond to stimuli, respond less accurately, give incorrect responses, or respond as time permits. It appears that the optimal presentation rate of information is task dependent. One experiment reported by Van Cott and Warrick (1972) gives an upper limit of 43 bits/sec. for a reading task. Optimal rates for other tasks need to be experimentally determined within specific situations.

An understanding of conceptual human information processing models and their applications to system design leads to a better human factors approach. Further research on human information processing is needed and can only provide valuable and exciting results.

THE CHANNEL CAPACITY OF SENSES FOR DIFFERENT UNIDIMENSIONAL STIMULI

SENSE	STIMULI DIMENSION	CHANNEL CAPACITY (BITS)	DISCRIMINABLE CATEGORIES
VISION	DOT POSITION (IN SPACE)	3.25	10
	DOT POSITION (IN SPACE)	3.2	10
	SIZE OF SQUARES	2.2	5
	DOMINANT WAVELENGTH	3.1	9
	LUMINANCE	2.3	5
	AREA	2.6	6
	LINE LENGTH	2.6-3.0	7-8
	DIRECTION OF LINE INCLINATION	2.8-3.3	7-11
	LINE CURVATURE	1.6-2.2	4-5
TASTE	SALT CONCENTRATIONS	1.9	4
AUDITION	INTENSITY	2.3	5
	PITCH	2.5	7
VIBRATION (ON CHEST)	INTENSITY	2.0	4
	DURATION	2.3	5
	LOCATION	2.8	7
ELECTRICAL SHOCK (SKIN)	INTENSITY	1.7	3
	DURATIONS	1.8	3

FIGURE 8 - VAN COTT & WARRICK, 1972, P. 28

The channel capacity of senses for multidimensional stimuli

Stimuli dimension	Channel capacity (bits)	Discriminable categories
Size, brightness, and hue (varied together)	4.1	18
Frequency, intensity, rate of interruption, on-time fraction, total duration, and spatial location	7.2	150
Colors of equal luminance	3.6	13
Loudness and pitch	3.1	9
Position of points in a square (no grid)	4.6	24

Figure 9 - Van Cott & Warrick, 1972, p. 29

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SUMMARY OF WORKSHOP INTERACTION

Conceptual Models of Information Processing

The phenomenon of chunking information provoked considerable interest during this workshop. Is chunking innate or learned? Both, according to the speaker. The ability to chunk information is innate, while the organization of that chunking is learned.

Information to be stored in long term memory (LTM) must be organized to make sense. How much rehearsal is necessary for something to stay in LTM?

Another question addressed the issue of whether people are becoming better parallel processors. The widespread use of video games today suggests that people have become better parallel processors.

In an attempt to apply the theories of information processing presented, a participant asked how the theories affect display rates. How quickly can one display information without losing the operator? Is the rate different for novices, experts? Right now there is no definite quantitative information on these questions. Current research indicates that display rate is task dependent.

TOP-DOWN METHODOLOGY FOR HUMAN FACTORS RESEARCH

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THE GEORGE WASHINGTON UNIVERSITY

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A Top Down Methodology For User-Interface Design*

The methodology we will present for designing user interfaces depends on viewing communications between a user and the computer as a conversation. This conversation would include inputs to the computer (outputs from the user), outputs from the computer (inputs to the user), and the sequencing in both time and space of those outputs and inputs. The conversation is viewed exclusively from the user's side of the conversation. That is, in our design process we are not concerned with how the conversation will be implemented.

Since we are viewing the user-computer interaction as a conversation, it is only natural to adopt a language model of the dialogue. We are actually modelling two languages, the one with which the user communicates with the computer and the language where communication flows from the computer to the user. Both languages can be said to exist on three levels; the semantic, syntactic and lexical. Natural languages can also be considered in these terms.

Before proceeding to the methodology, we must define some language terminology. Exhibit 1 gives the definition of the linguistic terms we will be using. Within the design framework, the terms can be exemplified as follows:

1. An input lexeme is represented by a single action with an interaction device such as a placement of a pick on a

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* This session was drawn largely from a portion of the course "Human Factors of User-Computer Interfaces", copyright 1981, Computer Graphics Consultants, Inc., 713 6th St., S.W., Washington, D.C.
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LANGUAGE TERMS

LEXEME (ALSO CALLED CHARACTER)

A SINGLE CHARACTER

LEXEMES HAVE NO MEANING

TOKEN

A SEQUENCE OF LEXEMES WHICH HAS A MEANING: A WORD

SYNTAX (ALSO CALLED GRAMMAR)

RULES FOR COMBINING TOKENS (WORDS) INTO "SYNTACTICALLY CORRECT" SENTENCES

SUCH SENTENCES NEED NOT BE MEANINGFUL

SEMANTICS

THE MEANINGS OF TOKENS AND SENTENCES

Exhibit 1

single keystroke on a keyboard. Output lexemes are single display elements such as a point, line, area or character.

2. An input token is a temporal sequence or collection of one or more user actions to form a unit of meaning such as a name, a position, an orientation or a value. An output token is a collection of display elements to form a meaningful token.

3. An input syntax would be the definition of how a sequence or collection of input tokens could form a command. An output syntax would be the definition of how output tokens (symbols) can be combined into a picture.

4. The semantics of the dialogue constitute the user's understanding of the meaning of all tokens, commands, symbols and pictures in the context of the application.

These three levels are organized into a processing model, a schematic of which is given in exhibit 2. Note the existence of feedback at all levels of the model. Lexical feedback is provided by echoing characters at the terminal or by moving a screen cursor to a new position. Syntactic feedback can be provided by a combination of well-phrased error messages to point out syntactic errors, and explicit acceptance of a well-formed command by echoing it. At the semantic level feedback can be achieved by either beginning to display the result called for by the command or, if that is impractical, by re-phrasing the command and printing it out (e.g. "A map of statues in downtown Washington, D.C. has been requested" after a user has specified location - Downtown D.C. and subject = statues to a mapping program).

PROCESSING MODEL

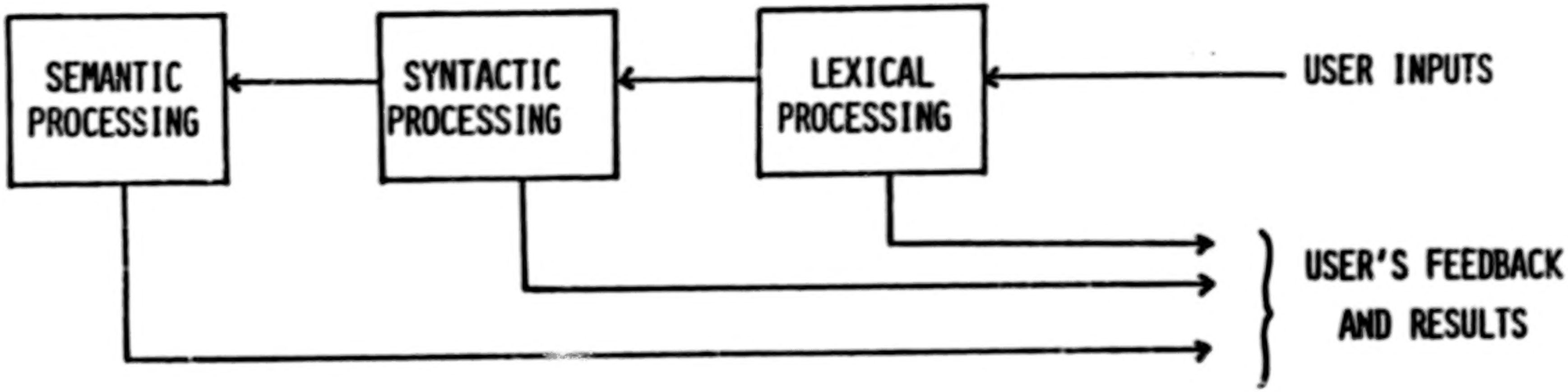
SEMANTIC PROCESSING
SYNTACTIC PROCESSING
LEXICAL PROCESSING
USER INPUTS
USER'S FEEDBACK AND RESULTS

Exhibit 2

Based on these linguistic concepts we will now present a top-down methodology analagous to modern programming methodology. Exhibit 3 is a outline of the methodology which we will follow one step at a time, developing an abbreviated example as we go.

Step one: Task Analysis. This is probably the most important step in methodology. (In fact it is so important that an entire workshop session has been devoted to task analysis and therefore it will not be explained in detail here.) Only with a thorough and detailed task analysis will a picture of the real "job" be formed. Results of this stage are a set of design constraints and objectives, a definition of user characteristics and a set of functional requirements. This information is all crucial if the design is to provide a realistic system which "fits both the job and the user.

Step two: Conceptual Design. Using the material we gathered in the task analysis, our next step is to do a conceptual design of the design of the system. In the conceptual design phase we identify the key concepts in the application. These concepts include the types of objects, and actions which may be taken on those objects or relationships. As an example, consider a typical MOR at Goddard. Types of objects might include spacecraft, computers, or, more abstractly, telemetry. Examples of relations between objects could be communications links, the relationship that part of the telemetry is status information on the health and well being of the space craft, and the fact the telemetry is communicated over a communications link.

TOP-DOWN DESIGN METHODOLOGY OUTLINE

- TASK ANALYSIS
- CONCEPTUAL DESIGN
- SEMANTIC DESIGN
- SYNTACTIC DESIGN
- LEXICAL (INTERACTION TECHNIQUE) DESIGN
- USER ENVIRONMENT DESIGN
- DESIGN REVIEW
- IMPLEMENTATION

Exhibit 3

The examples I have just given are not very specific, but they do illustrate what we mean by objects, relations and actions. The whole purpose of the conceptual design is to identify and categorize these key concepts in terms of the user's view of the system. Once we have satisfied ourselves that we have a complete conceptual design, we are ready to move on to the next step in the design process.

Step three: Semantic Design. Our next task is to design the units of meaning conveyed between the user and the computer but not the form in which those units are conveyed. Examples of units of meaning are commands which operate on objects or relations betwen objects. From the computer to the user the semantic design would incorporate the selection of information to be presented to the user. More specifically, we mean the content of the information but not the form of that information. Returning to our MOR example, user to computer semantic units might include the command vocabulary available to an operator. A computer to user example might be the selection of which information to include in the telemetry.

Step four: Syntactic Design. Now that we have decided which units of meaning we wish to convey between the user and the computer, our next step is to design the form in which those units will be conveyed. From the user to the computer, this constitutes deciding on a command language grammar. From computer to user this would include positioning the information on various output devices and deciding on the form of the information, for example whether to use graphics or text. Returning once again to the MOR example, this could mean deciding which CRT screen to display a specific piece of information on as well as designing a language for command input.

Step five: Lexical Design. At this stage we are finally ready to consider hardware. Note that to this point, we have been discussing form and content of the user computer dialogue, but we have not yet considered physical input and output devices. During the lexical design phase, we consider the hardware capabilities we have available to us and decide how to bind them to the words in our input and output languages. For user to computer language, we would look at such input devices as keyboards, touch panels, voice recognizers, and graphic tablets. We would also consider the interaction techniques, that is the sequence and combination of uses of input devices, necessary to carry out a command input. For the computer to user language, we would select such output primitives and attributes as line style, color,text fonts, and perhaps voice synthesis. In lexical design, we are typically constrained by hardware availability, but within such constraints we strive to use interaction techniques that are natural for the user, efficient in terms of time and effort, and consequently minimize errors. At this point we have completely specified in every detail both the user-computer and the computer-user languages. We have not yet, however, completed our design process.

Step six: User Environment Design. During this phase of the design, we look at the environment in which the user will be functioning. This includes both the mental environment and the physical environment. In mental environment, we include such things as reference manuals (which were of course developed during the previous steps), user's manuals, and pocket reference guides also known as "cheat sheets." In the physical environment, we include the physical structure of the work area, the design of chairs, tables, other work surfaces, computer terminals, etc. Lighting and sound characteristics of the work area, appropriate temperatures, and some customizing for individual operators (for example, we may wish to design a work station for a left or right-handed person).

Step seven: Design Review. The final stage in our design methodology is of course a complete review before implementation begins. In order to accomplish this review we must have a detailed formal design specification which would include the user's manual and reference manuals mentioned above. We must have means of evaluating the design, and this is most difficult at the current time. We do have some design guidelines, particularly for design of the physical environment, but detailed guidelines for designing the interaction languages do not yet exist. One of the thrusts of our research projects at Goddard, is to develop such detailed design guidelines. Another problem with evaluating the design is the lack of good metrics for measuring such characteristics as goodness, efficiency, or user friendliness of interaction languages. Coincidentally, the development of such metrics is another thrust of our research. Even though we cannot yet apply detailed and specific measurement to the evaluation process, we can identify many potential problems by walking through various interaction scenarios. This can be accomplished by paper walk throughs using a formal design specification, or by simulating interaction scenarios in software for more realistic walk throughs. At the conclusion of the design review , the whole design process can be repeated as many times as necessary until a satisfactory design is achieved.

Exhibit 4 is a summary of the top-down methodology, presented in slightly different form. We see that our first phase is an analysis phase where we attempt to understand the user's view of the application. We next must define design goals so that we will ultimately be able to evaluate our design. Then we synthesize the results of our analysis and our definition using a top-down approach to produce a systems design. We then enter the evaluation phase and based on the results of our evaluation iterate to a satisfactory design. Fianlly, we proceed to implement the design. But in implementing the design we take care to structure so that it will be easy to change because no matter how carefully we've followed our design process, we won't be perfect the first time.

In conclusion, the concepts and procedures presented in the proceeding pages are admittedly general and cannot be followed precisely. They are presented to introduce the reader to a general approach to the the problem of human computer dialogue design. As our research progresses, we hope to be able to provide substantially more detailed procedures for approaching this design problem. In the meantime, we hope the approach described here will provide insights into the difficulties of the design process.

SUMMARY OF TOP-DOWN METHODOLOGY

- ANALYZE
    - KNOW THE USER (INTERDISCIPLINARY TEAM)
    - QUESTION (DON'T BELIEVE ALL THE ANSWERS)
    - OBSERVE
- DEFINE DESIGN GOALS
    - PRODUCTIVITY
    - USER SATISFACTION
    - COST
- SYNTHESIZE
    - DEVELOP CONCEPTUAL MODEL PRESENTED TO USER
    - DEFINE SET OF USER COMMANDS AND RESPONSES THERETO (SEMANTICS)
    - DEFINE GRAMMAR (SYNTAX)
    - DEFINE INTERACTION TOOLS & TECHNIQUES (LEXICAL)

Exhibit 4

- EVALUATE
  - USE DESIGN PRINCIPLES
  - REQUIRES A DESIGN DOCUMENT WITH ALL DETAILS OF MAN-MACHINE INTERFACE
  - SCENARIOS, FORMAL SPECIFICATIONS ARE HELPFUL
- ITERATE TO SATISFACTORY DESIGN
- IMPLEMENT
  - AFTER ALL ASPECTS OF MAN-MACHINE INTERFACE ARE DEFINED
  - STRUCTURE FOR CHANGE, BECAUSE IT WON'T BE PERFECT THE FIRST TIME
  - HUMAN FACTORS "FINE TUNING"

Exhibit 4 (cont'd)

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SUMMARY OF WORKSHOP INTERACTION

Top-Down Methodology for Human Factors Research

During the course of this workshop, Dr. Sibert asked the participants for examples from Goddard work that would serve as an basis for a conceptual design. They suggested an MOR controller observing passes, seated in front of a terminal. Within the framework of conceptual design, these examples include types of objects (spacecraft health and safety), also relations between objects (telemetry, spacecraft safety), and actions on objects (commands).

A section concerning personality types (adaptable/rigid) evoked a series of questions. In terms of ultimate success of the users, it was felt necessary to inform implementers of problems at Goddard concerning user input so they can be flexible in their design.

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THE HUMAN AS SUPERVISOR IN AUTOMATED SYSTEMS

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THE HUMAN AS SUPERVISOR IN AUTOMATED SYSTEMS

Introduction

Since the industrial revolution human beings have played a critical role in the control of systems. Historically it has been the human operator who has "closed the control loop" (Figure 1): that is, it is the human operator who has been responsible for closely monitoring the process or system, giving new commands to change or alter the current system state, and evaluating the output of the system in order to ensure that the sequence of commands has brought the system to the desired state.

The human's relation to the control system or, even more primitively, to the controlled variable, has changed and become more and more indirect over time. Kelley (1968) depicts the process in Figure 2. In the most rudimentary systems, a human changes the environment or controlled process by direct use of his/her body's muscle power. In a more sophisticated process, the human's power is applied to a tool which in turn changes the controlled process. The nature of human control in this case is likely to be more effective, but it is certainly less direct. With the industrial revolution comes the possibility of adding an external power source and, thus, even more dramatically changing the nature of human control: the human is now responsible for regulating the power source which affects changes in the system. The relationship of the human to the controlled system now becomes even more indirect. The types of control actions change as the relation between the process being controlled and the human change. In general, there is a decreased use of the human's muscular strength and an increase in the use of his/her intelligence and senses. These new responsibilities of the human controller require new types of feedback information and, thus, new information displays.

Automation in the Control Process

All the control systems discussed thus far can be thought of as manual control

"Man-in-the-Loop" Control System

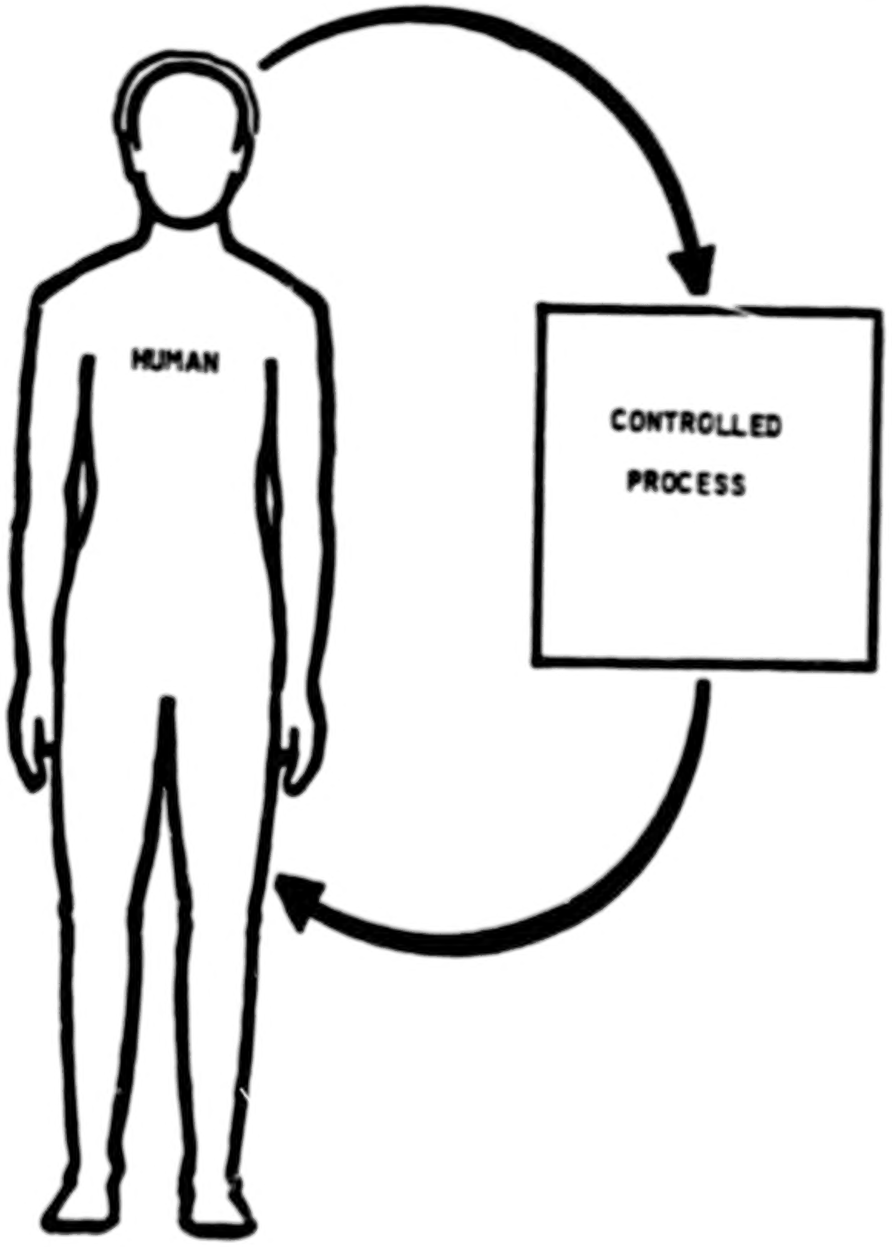

HUMAN
CONTROLLED PROCESS

Figure 1 (Kelley,1958)

Primitive Control System

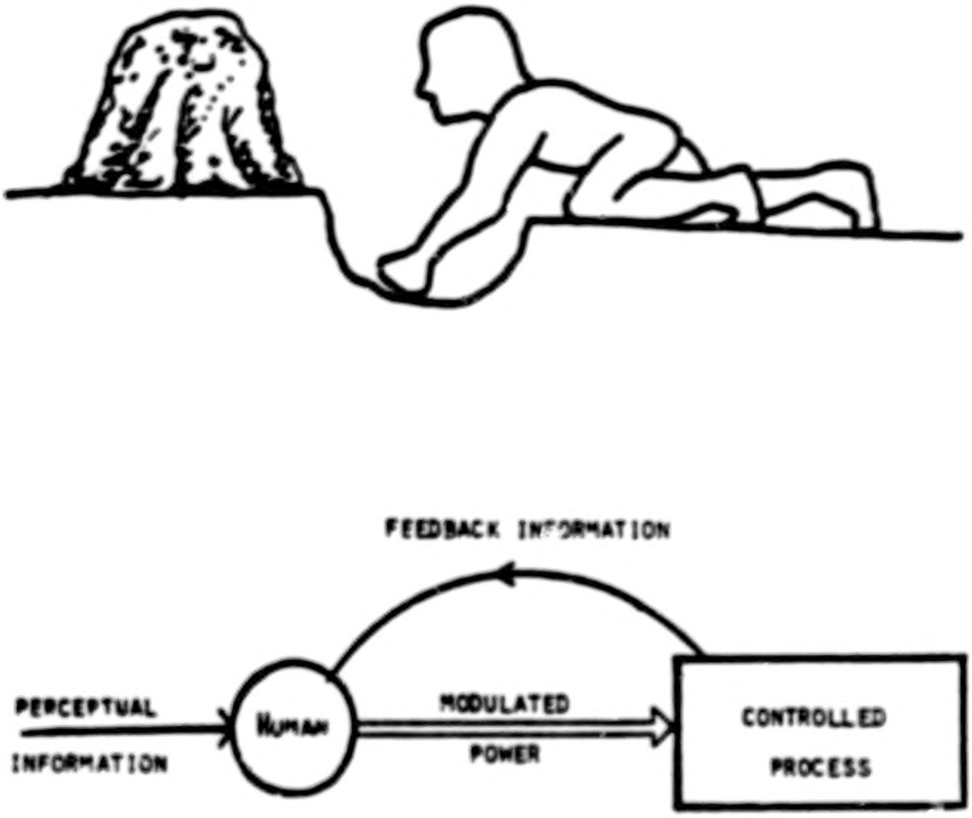

FEEDBACK INFORMATION
PERCEPTUAL INFORMATION
HUMAN
MODULATED POWER
CONTROLLED PROCESS

Figure 2A (Kelley,1968)

Intermediate Control System

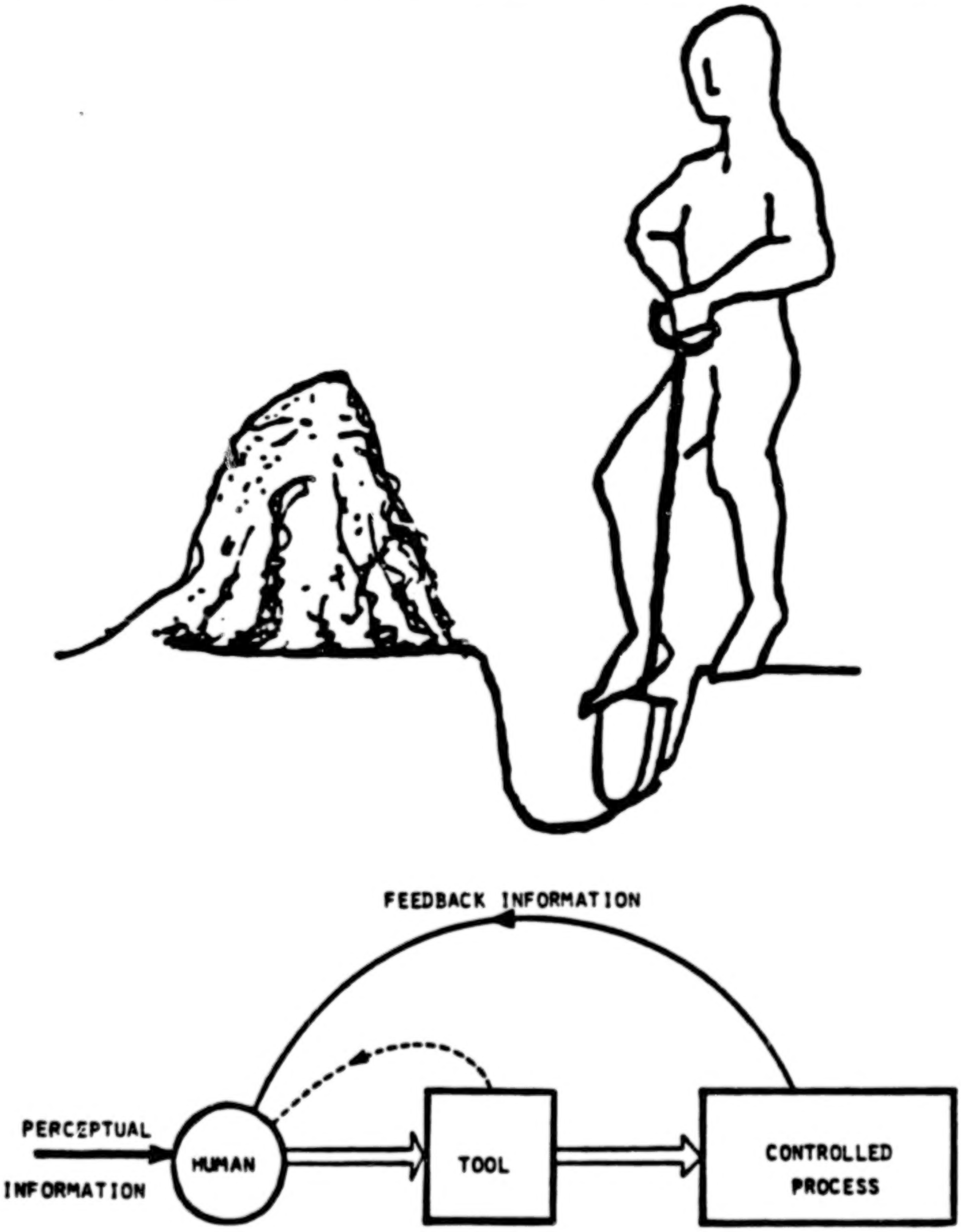

FEEDBACK INFORMATION
PERCEPTUAL
INFORMATION
HUMAN
TOOL
CONTROLLED
PROCESS

Figure 2B (Kelley,1968)

Advanced Control System

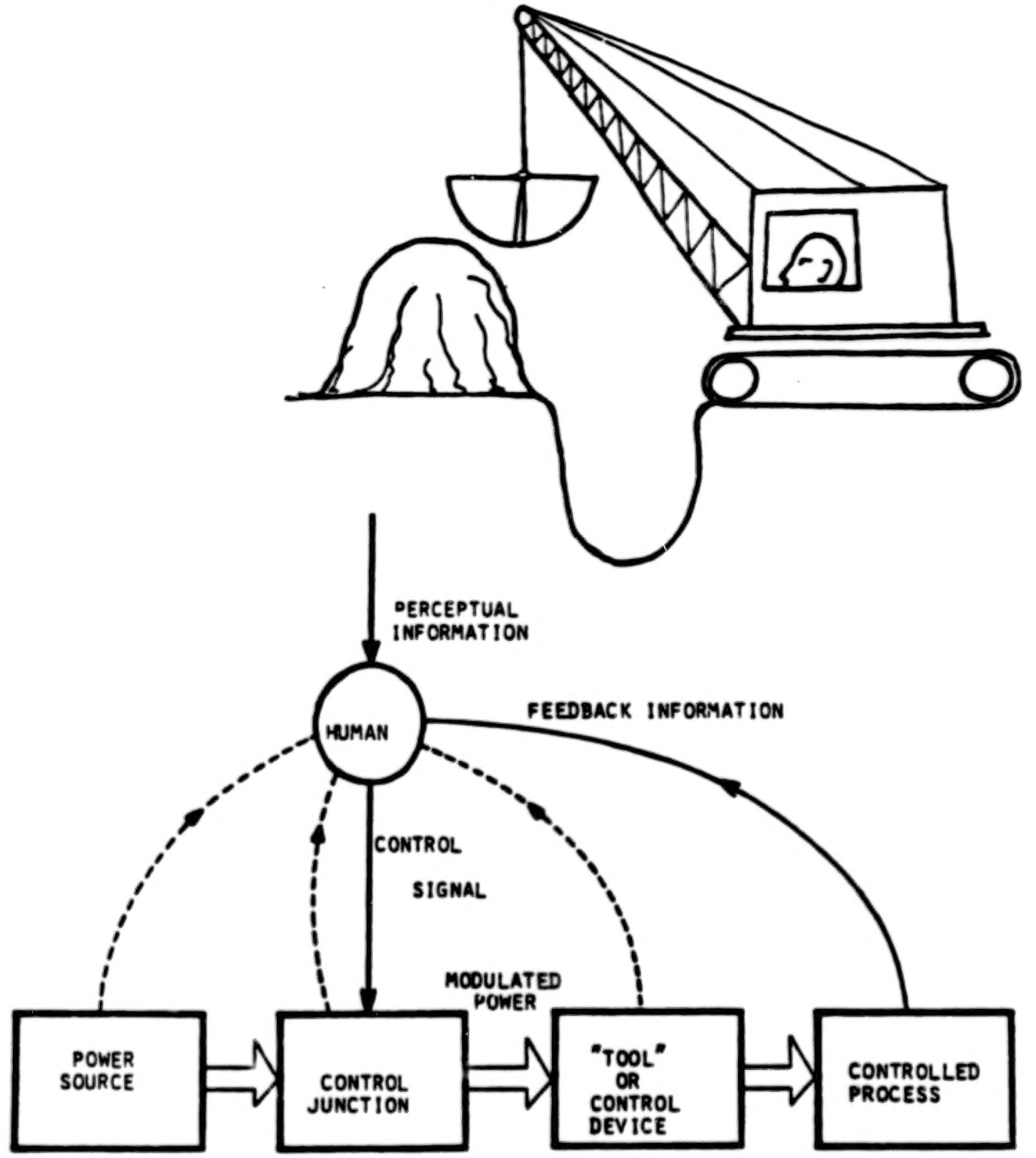

PERCEPTUAL INFORMATION
HUMAN
FEEDBACK INFORMATION
CONTROL SIGNAL
MODULATED POWER
POWER SOURCE
CONTROL JUNCTION
"TOOL" OR CONTROL DEVICE
CONTROLLED PROCESS

Figure 2C (Kelley, 1968)

systems. These are systems in which the human, though affecting the process by means of intermediate devices and with the help of external power sources, is intimately involved in a continuous and dynamic way with the control system. Increasingly, and at an increasing rate, automation is being introduced into the control process. The result is that the human's relation to the control system is even more indirect and will result in new tasks, new information needs, and new control activities (Figure 3). In an automated or semiautomated system, the human operator communicates with a computer or banks of computers which in turn take over the direct control of the process.

Before exploring the impact of automation on the role of the human operator, it might be helpful to review some of the reasons for the increased automation in control systems. Rouse (1981) suggests several reasons. Fundamentally, there is a desire for improved performance. By automating a system, it is hoped that the system will support a higher workload (e.g., an airport can support more aircraft with automated air traffic control facilities; MSOCC-1 can support an increased number of missions; a data processing operation can support more volume or a wider variety of application tasks). Safety and human dignity are also reasons. Computers replace human operators in tedious, unpleasant, and hazardous tasks (e.g., file maintenance, sorting and other clerical tasks, exploring deep space.) Computers provide warning and alarm systems which build a higher degree of safety into the system than was previously possible. There are also some tasks which computers do better than humans, and the shift of responsibility of such tasks to a computer system will also increase system safety and reliability (e.g., continuous monitoring of slowly changing variables in order to detect out-of-range or degraded conditions). Economic considerations also motivate the increasing use of automation. Replacing humans or augmenting human capability by means of computer assistance may allow system efficiency to increase with the same staff level or decrease system cost by decreasing the number of required personnel. Finally, it must be admitted that sometimes automation is introduced into a controlled

Automated Control System with a Human Supervisor

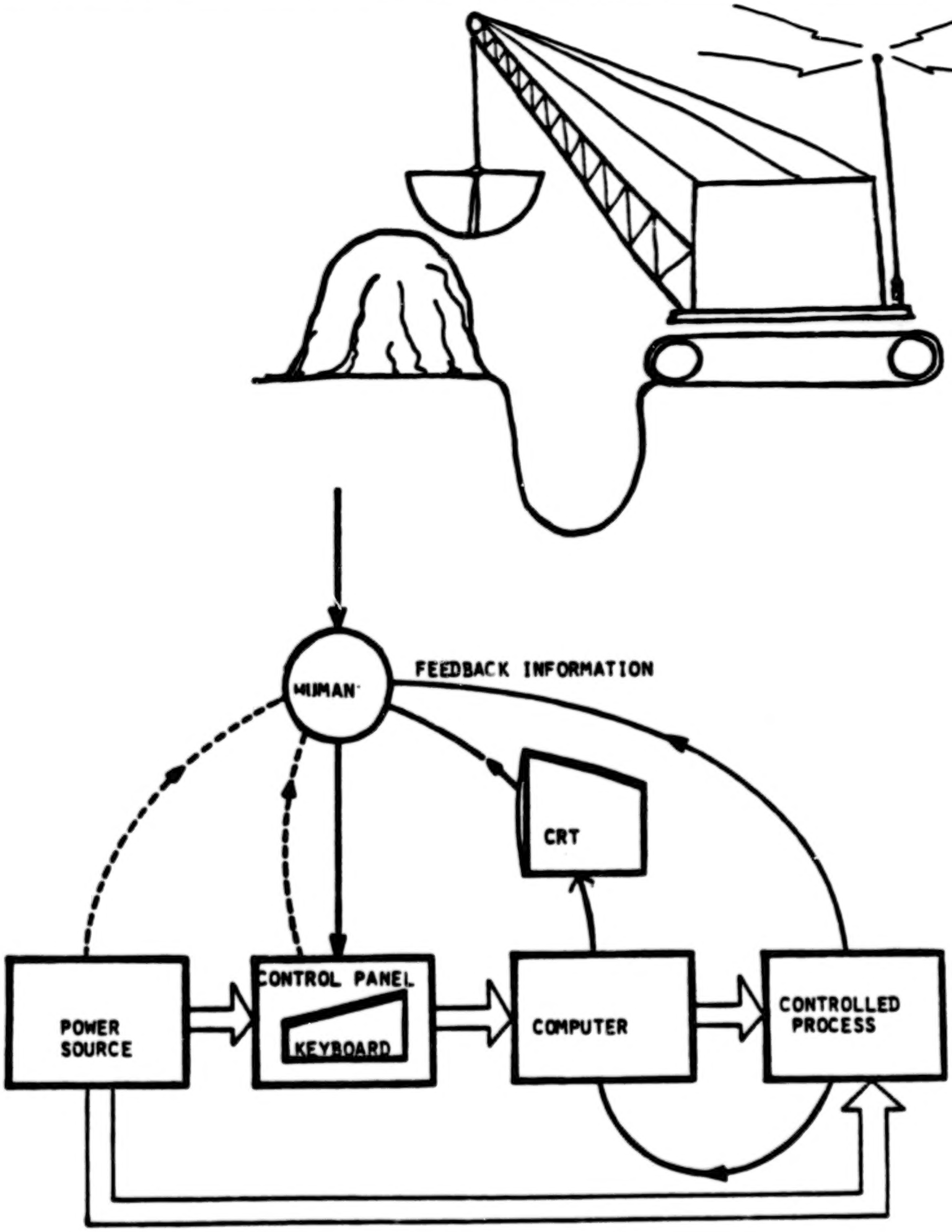

HUMAN
FEEDBACK INFORMATION
CRT
CONTROL PANEL
KEYBOARD
POWER SOURCE
COMPUTER
CONTROLLED PROCESS

Figure 3 (Sheridan & Johannsen, 1976) system simply because it's there. The hardware for automation has advanced much more rapidly than design principles to guide its implementation (Mitchell, 1980). It is often unclear when or if to implement some facet of automation. Sometimes automation is introduced for the rather fuzzy and certainly indefensible reason that it will make the system modern or "state of the art".

The Role of the Human Operator in Automated Control Systems

Most studies of automation in the control process concur: the result of increased automation in the control room and in other previously manual processes does not imply the human operator is being replaced but rather that his/her role is changing from a direct controller to that of a system supervisor who monitors and directs the computer which carries out the moment to moment control functions (Rouse, 1981; Sheridan and Johannsen, 1976). The human operator is now responsible for supervisory rather than manual control of the system.

There are a number of design issues for systems which will include some degree of automation. Fundamentally, the question of whether to automate at all must be addressed; subsequently, if the decision to automate is made, the system designer must determine the appropriate allocation of tasks between the human and computer as well as devise the appropriate mechanisms to allow efficient human-computer dialogue.

Whether to Automate

The decision about whether or not to automate all or a portion of a control task is important. Reasons supporting automation need to be clearly articulated. Implications of automating particular tasks should be studied and evaluated. Technology has now reached the level where it is possible to automate many control functions. However, it is not clear whether these functions should be automated, taking into consideration various human factors issues (Boehm-Davis et al., 1981). In a NASA sponsored workshop entitled

"Human Factors of Flight-Deck Automation - NASA/Industry Workshop", the question of whether or not to automate particular functions was critically addressed by a panel of participants representing the Man-Vehicle Systems Research Division at NASA-Ames, the Federal Aviation Administration, the Royal Air Force, airline companies, aircraft manufacturing companies, universities, and consulting firms. The participants generally agreed that technology is now sufficiently advanced so that it is theoretically possible to automate most systems. Although automation has many benefits, the workshop participants identified a number of automation-induced problems which, though discussed in the context of aircraft flight decks, are relevant to a wide variety of systems. These problems include:

- Violation of benefits - Problems are created whenever the automated system does not provide the projected benefits (e.g., less reliable, more costly to operate, creates a heavier workload than manual system it replaces, creates decreased safety margin or diminished quality of life).
- Credibility - Failure of automated equipment to function as expected leads to credibility problems. Users who do not trust the system may use it in a less than optimal manner.
- Training - Personnel using automated systems must often receive training as both a system supervisor for his/her role when the system is functioning automatically and as a manual controller for emergency or degraded conditions. These two roles are not necessarily compatible or complementary; at times, the roles may require two disjunctive sets of knowledge and operating skills.
- System Use - When an automated system is functioning properly, the human operator is reduced to a system monitor. This role may leave the human, particularly highly skilled operators, bored and/or complacent.

These issues are rarely discussed in the context of automation, yet they are critically important. In evaluating the costs and benefits of introducing automation into a system, these issues must be clearly and thoroughly addressed. Automation-induced problems may not often outweigh the benefits of automation and to automate may be the most reasonable decision; however, the decision to automate does not abrogate the issues; it merely shifts the burden to system designers who must eliminate or ameliorate the adverse effects.

Human Factors Issues in Automated Man-Machine Systems

The human factors issues in the design of automated man-machine systems can be grouped into three areas: the definition of reasonable and meaningful roles for the human operator, allocation of tasks between computer and human system components, and the creation of interfaces which facilitate the human-computer dialogue.

The first two areas are highly related and are likely to be addressed simultaneously in the design process. Creating a meaningful and reasonable role for the human operator results from taking a particular perspective at some point in the design process. The perspective is an operator-centered view of the total system aimed at trying to understand the set of responsibilities assigned to the operator and the dynamics of his/her interaction with the system. One useful tool for gaining this type of perspective is to conduct a task analysis which carefully analyzes the human operator's sequence of tasks; a task analysis includes identification of the individual tasks, the pace of the operations, and underutilized operator resources.

The traditional design approach is often system-centered with the result that, although the overall system, at least theoretically, functions adequately, the tasks assigned to the operator are those which are "left over" or not amenable to automation. The human operator has traditionally functioned as the flexible component in the control loop. It often happens that no one closely examines the overall operator role which the set of left over tasks implicitly define.

A proposed MSOCC-1 automation plan is a case in point (Mitchell, 1981). The proposed configuration of an automated MSOCC-1 is an exciting use of technology and will drastically reduce the amount of direct manual intervention in the DOC (Data Operations Controller) and computer operations areas. The staffing plan, however, calls for maintaining or possibly increasing the current staff. It is unclear, however, what the eight to ten people per shift will do as the majority of their current functions will be automated. Currently, computer operators transport, mount, and dismount mission-specific software resident on disks and tapes. Under the proposed automation plan, this activity will be fully automated. The responsibilities of the DOC operator are also unclear. Figure 4 depicts a scenario which was given in an MSOCC-1 Operations Requirements Study (TM-81-6098). The scenario represents the anticipated human-computer dialogue during a satellite pass preparation. Examination of the scenario reveals that the only active human input is to type the word "GO" as the second to last step in the sequence. An alternative version of this scenario eliminates even this step, assigning the operator to a completely passive, monitoring role. Analysis of this situation from an operator-centered perspective raises a number of questions about the reasonableness of the role assigned to the human.

The MSOCC-1 scenario raises a number of issues about the place of the human operator in an automated system. Often, there is a tendency to retain the operator as the final redundancy in the control loop to ensure fail-safe conditions. Sometimes this is indicative of an underlying distrust of automation - a questionable premise in a highly automated environment. The consequences of the misgivings can be severe. The first-order impact is cost. Labor costs constitute a large percentage of a system's operating budget. Building a human backup for every system may be a costly proposition, one not offset by benefits received.

A second-order impact directly addresses the anticipated benefits. In many automated systems, the tasks allocated to the operator approach the trivial, yet the operator responsibilities are increased. In the example, the operator performs a perfunctory task and rarely interacts with the system in a meaningful way. Yet in an emergency, the operator is expected to revert to manual control, and it is questionable whether, in this case, he/she will have the capability should the need arise. The questions then are, "What should the human do in automated systems? How should tasks

HUMAN - COMPUTER DIALOGUE FRAGMENT

FROM THE PROPOSED AUTOMATED MSOCC-1

Statement Source	Time Tag	Item Number	Control Statements	Comments
SCHEDULE	186:20:16:10	1	DI SAMA	Display PROC SAMA
SCHEDULE		1.1	CO LN1 TO TAC6	These items displayed from PROC
SCHEDULE		1.2	CO TAC6 TO AP5	
SCHEDULE		1.3	CO AP5 TO KCRT (MOR1)	
SCHEDULE		1.4	CO AP5 TO SCR (MOR1)	
SCHEDULE		1.5	DLL SAMASYS TO AP5	Downline load SAM-A software to AP5
SCHEDULE		2	WAIT	Wait for operator intervention
KEYBOARD		3	GO	Operator key-in
SCHEDULE		4	S SAMA	EXEC SAMA

DOCS Operator–Computer Interaction Scenario for Automated MSOCC–1 Operations

FIGURE 4

be allocated to achieve optimal use of both the system's human and computer resources?"

Optimal allocation implies measurement with respect to some criterion. Possible objectives include maximizing speed of response, minimizing deviations of important variables, maximizing safety, and minimizing time until recovery from failure is achieved. Quantifying such attributes is often problematic. Moreover, the time interval over which measurement is made will affect the measurement. There are many tasks which a human performs as well as, or perhaps even better than, a computer for a few minutes or hours but which are intolerable and result in degraded human performance over a long period of time.

There are several different approaches to task allocation. One interesting approach that is receiving increased research attention is dynamic as opposed to static allocation of tasks (Rouse, 1975; Rouse, 1976; Rouse, 1977; Chu and Rouse, 1979). This approach is based on the premise that there are many tasks which can be adequately handled by either the computer or the human operator. The allocation rule is based on the principle that a particular task is allocated to the controller (human or computer) with the most resources available at the time. There are a number of theoretical questions which this approach involves. A major issue is to decide who is in command: the human or computer. Another issue is to decide how the human communicates to the computer what he/she is doing or plans to do next. These issues are still in a highly speculative domain but merit serious additional research.

The other alternative, static task allocation, although simpler, is by no means trivial. There are many fuzzy issues in this area as well. The normal approach requires an assessment of the respective strengths and weaknesses of the human and computer components. This assessment is normally made in light of prevailing theories about human capabilities and cutting edge computer technologies. As hardware changes and the skills of the human operator become better understood, this assessment changes.

The commercially available computer hardware is capable of only limited intelligence. Over the next decade, as artificial intelligence research expands the capability of knowledge–based systems, computers may become more flexible, creative system components. Currently, however, the computer component's strengths are its speed of performance and its reliability.

Computers are very fast compared to human processing in most routine tasks. Reliability is possibly an even stronger asset. Given a set of instructions, a computer tirelessly performs a given task or set of tasks. It is reasonable to expect a computer to perform at the same level of efficiency at the end of a shift as at the beginning. Computers offer a consistency of performance at even the most tedious tasks that even the most skilled human operator would find next to impossible to emulate.

Two related questions arise: Why keep the human in a complex system? Why not completely automate the system? Rouse (1982) answers these questions very simply: "The possibility of failure is the primary reason for having humans monitor automatically controlled processes. If hardware and software failures could not occur and if automation were capable of handling all contingencies then human operators would be unnecessary". Given the limitations of current technology and the adaptability of humans, the human operator brings a number of critical attributes to the control systems which are not matched by computer components. Crawford et al (1977) summarized human attributes as follows:

- Humans have extensive heuristic information processing capabilities which can not be duplicated by machines; a human is able to apply creative solutions to unique problems and eliminate large numbers of alternatives during the solution process (i.e., the human is adaptable). The computer can complement this process by lending its speed to search and retrieve stored information based on the human's direction and guidance.

- Human's problem-solving processes seem to contain random elements which enable him/her to attempt solutions which are not a direct result of standard rule following procedures; he/she is able to innovate and, thus, can arrive at unpredictable but successful results. The computer can provide support in this "ideation" activity by recording the human's output and providing a medium for generating novel relationships.

- Human pattern recognition skill is generally superior to a computers particularly for new or rare events. Humans are quick to recognize degrading conditions.

- The human has a nearly limitless capacity for behavioral variety; this is reflected in the unique capability for innovaton, orginality, and creativity.

Before examining the role of humans in control systems it is helpful to also consider some of the known limitations of the human component (Crawford et al., 1977).

- A human requires a certain minimum amount of time in which to consolidate his/her thoughts (i.e., perform complex processing).
- A human is a poor parallel processor. A human has limited sensory and cognitive ability to deal with incoming information, particularly multiple sensory inputs. As a result, a human performance tends to be degraded when he/she is asked to perform several tasks in parallel, especially if they are in multiple stages of completion.
- A human has a finite and limited channel capacity, easily suffering from information overload. This is a distinct danger in increased task complexity.

Good system design will explicitly take the strengths and limitations of both the human and computer components into account, drawing on the respective strengths and minimizing the demands on the weaknesses.

Based on the assumption that system failures and design limitations are quite possible, it is suggested that the primary responsibilities of the human in complex systems are to monitor the system, detect abnormal conditions, and diagnose the cause of system failure (Rasmussen and Rouse, 1981). Furthermore, it may be assumed that for many automated systems, the human operator will be expected to operate in a dual mode: as a system supervisor and monitor when the system is functioning automatically and as a manual controller in times of system failure.

One immediate problem that the bimodal responsibility creates is that the human now has two different and perhaps quite disparate roles, potentially requiring two different sets of skills and two different views of the system. In automatic mode, the human needs a high level, integrated overview of the system, whereas in manual mode the human needs to have an understanding of the system which is detailed, thorough, and "nitty-gritty".

A good deal of experimental and theoretical research suggests that human understanding of a complex system is guided by an internal or "mental" model of the system built up by the operator over time. The adequacy of the internal model will govern the timeliness and appropriateness of an operator's responses. One of the difficulties of the two mode function of the human in complex systems is that the varying sets of responsibilities suggest that the operator needs to build up multiple internal models of the system in order to integrate his knowledge of the system and to guide his control actions. It is likely that a skilled operator in a highly automated system must build up a hierarchy of internal models, encompassing a set of system views which vary from a very general and broad system overview to a variety of very specific and detailed models of particular subsystems.

Recent research has demonstrated that information displays can help or hinder the development of an operator's internal models (Mitchell, 1980). In traditional, hardwired dedicated displays, there was little choice about information display design. Each hardware device, data channel, or sensor generated a data item which was individually displayed to the operator (e.g., the battery, the voltage regulator). Control room designers could choose how to display the data (dials, bar graphs, needles, etc.) and could arrange the set of displays on control panels but had no opportunity to selectively display data, to group or aggregate it into higher level summaries. In essence, the displays, due to limitations of technology, were directly tied to the lowest level hardware subsystems (Figure 5). Traditional displays placed a tremendous burden on the human operator. Essentially, the human was responsible for monitoring, at times, vast amounts of displayed data, selecting out relevant items, then combining and integrating the low level data into meaningful forms compatible with his/her higher level information needs.

The advent of computer-based displays eliminated the need for this type of display but not necessarily the practice. Computer-based displays allow data to be filtered, PORTION OF A 747 PILOT PANEL

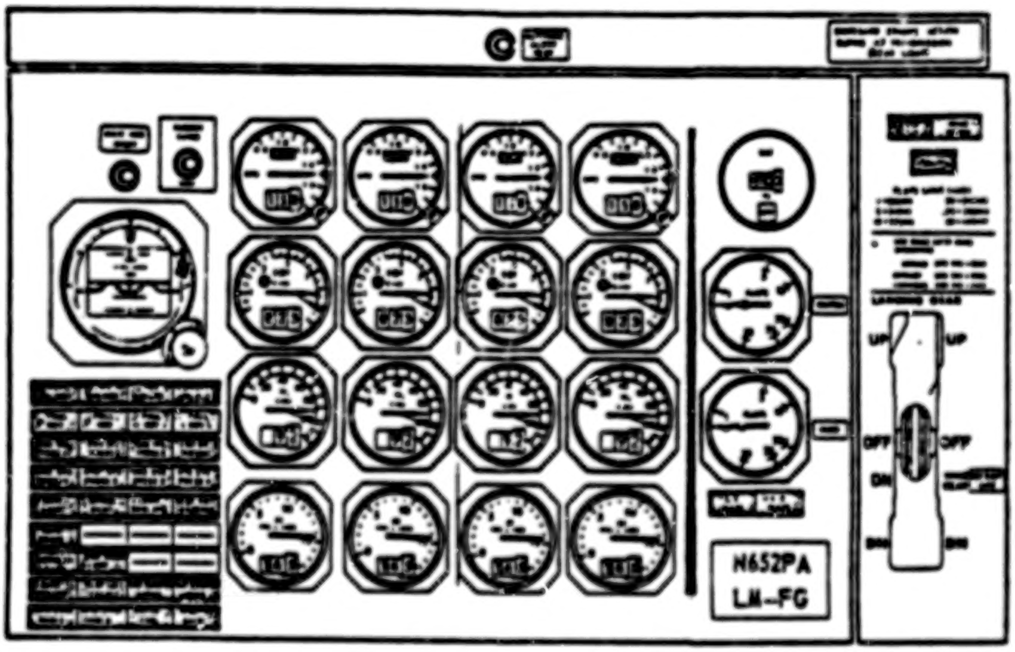

N652PA
LM-FG
UP
UP
OFF
OFF
ON
DN
DN

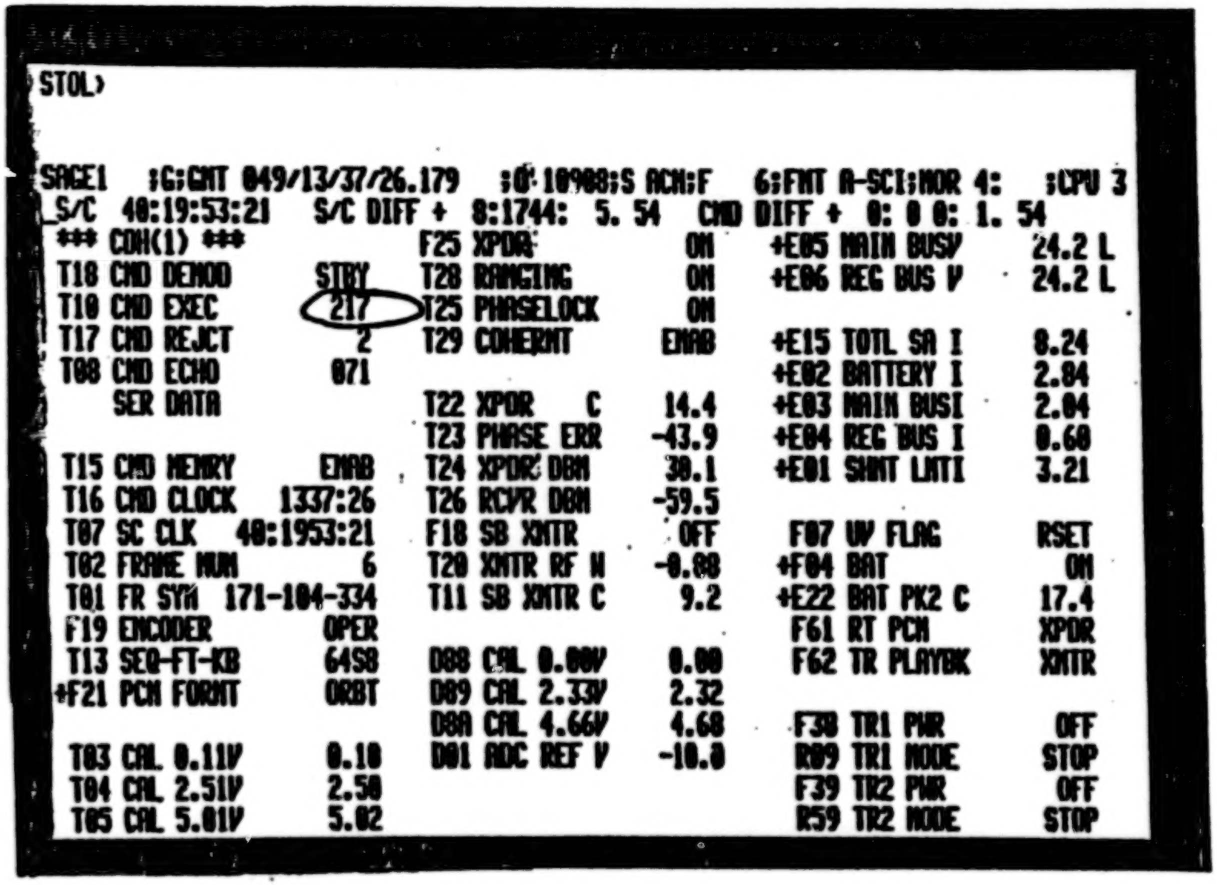
FIGURE 5

summarized or aggregated, and displayed in forms limited only by the imagination of the designer. Unfortunately, perhaps because it is easier, many computer-based displays simply use the CRT as a new medium on which to display "the same old data in the same old mode" (see for example, Figure 6). As early as 1975, Braid warned "...there is an alarming tendency . . . to propose replacement of the dedicated conventional instruments by a few dedicated electronic displays . . . Such proposals ignore the flexibility that electronic displays offer."

The issue is really one of design: How do you use the flexibility of the computer to best create displays? One strategy is to use the flexibility to present information in forms which are compatible with the users' mental models of the system. In highly automated systems, it is likely that the operator has at least two sets of internal models: one which allows him/her to function as a monitor and system supervisor, and a second which allows him/her to function as a manual controller. This possibility suggests that perhaps, at the very least, the control room of an automated system ought to have two sets of displays which the operator can transition between: one set giving a high level system overview, the other giving detailed views of individual subsystems.

An Example of Hierarchic Information Displays

In order to illustrate some of these concepts of display design, a simulated system used in some theoretical and empirical research at the Ohio State University will be described. The experiment simulated a conveyor system in which engines were routed in and out of various check points. Depicted in Figure 7, the system had engines arriving at station 1, the diamond labelled "1", which the controller routed either into Buffer Storage or on to Station 2. Once at Station 2, the engine needed to go to the Test Station, Station 6, passing through Stations 3 or 4. Once tested, an engine was either routed out the system through Station 3 or into the Repair Station, depending on the outcome of the test. The system was highly constrained, allowing no more than one



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STOL>


SAGE1   ;G;GMT 049/13/37/26.179   ;0 10908;S ACM;F   6;FMT A-SCI;MOR 4:   ;CPU 3
_S/C  40:19:53:21    S/C DIFF +  8:1744:  5. 54   CMD DIFF +  0: 0 0: 1. 54
 *** CDH(1) ***                 F25 XPDR             ON      +E05 MAIN BUSV       24.2 L
 T18 CMD DEMOD          STBY    T28 RANGING          ON      +E06 REG BUS V       24.2 L
 T10 CMD EXEC            217    T25 PHASELOCK        ON
 T17 CMD REJCT             2    T29 COHERNT        ENAB      +E15 TOTL SA I       8.24
 T08 CMD ECHO            071                                 +E02 BATTERY I       2.84
     SER DATA                   T22 XPDR     C     14.4      +E03 MAIN BUSI       2.04
                                T23 PHASE ERR     -43.9      +E04 REG BUS I       0.60
 T15 CMD MEMRY          ENAB    T24 XPDR DBM       30.1      +E01 SHNT LMTI       3.21
 T16 CMD CLOCK       1337:26    T26 RCVR DBM      -59.5
 T07 SC CLK     40:1953:21      F18 SB XMTR         OFF       F07 UV FLAG         RSET
 T02 FRAME NUM             6    T20 XMTR RF W     -0.88      +F04 BAT               ON
 T01 FR SYN  171-104-334        T11 SB XMTR C       9.2      +E22 BAT PK2 C       17.4
 F19 ENCODER            OPER                                  F61 RT PCM          XPDR
 T13 SEQ-FT-KB          64S8    D08 CAL 0.00V      0.00       F62 TR PLAYBK       XMTR
+F21 PCM FORMT          ORBT    D09 CAL 2.33V      2.32
                                D0A CAL 4.66V      4.68       F30 TR1 PWR          OFF
 T03 CAL 0.11V          0.10    D01 ADC REF V     -10.0       R09 TR1 MODE        STOP
 T04 CAL 2.51V          2.50                                  F39 TR2 PWR          OFF
 T05 CAL 5.01V          5.02                                  R59 TR2 MODE        STOP
```

MSOCC SAGE DISPLAY

FIGURE 6

BEST DOCUMENT AVAILABLE

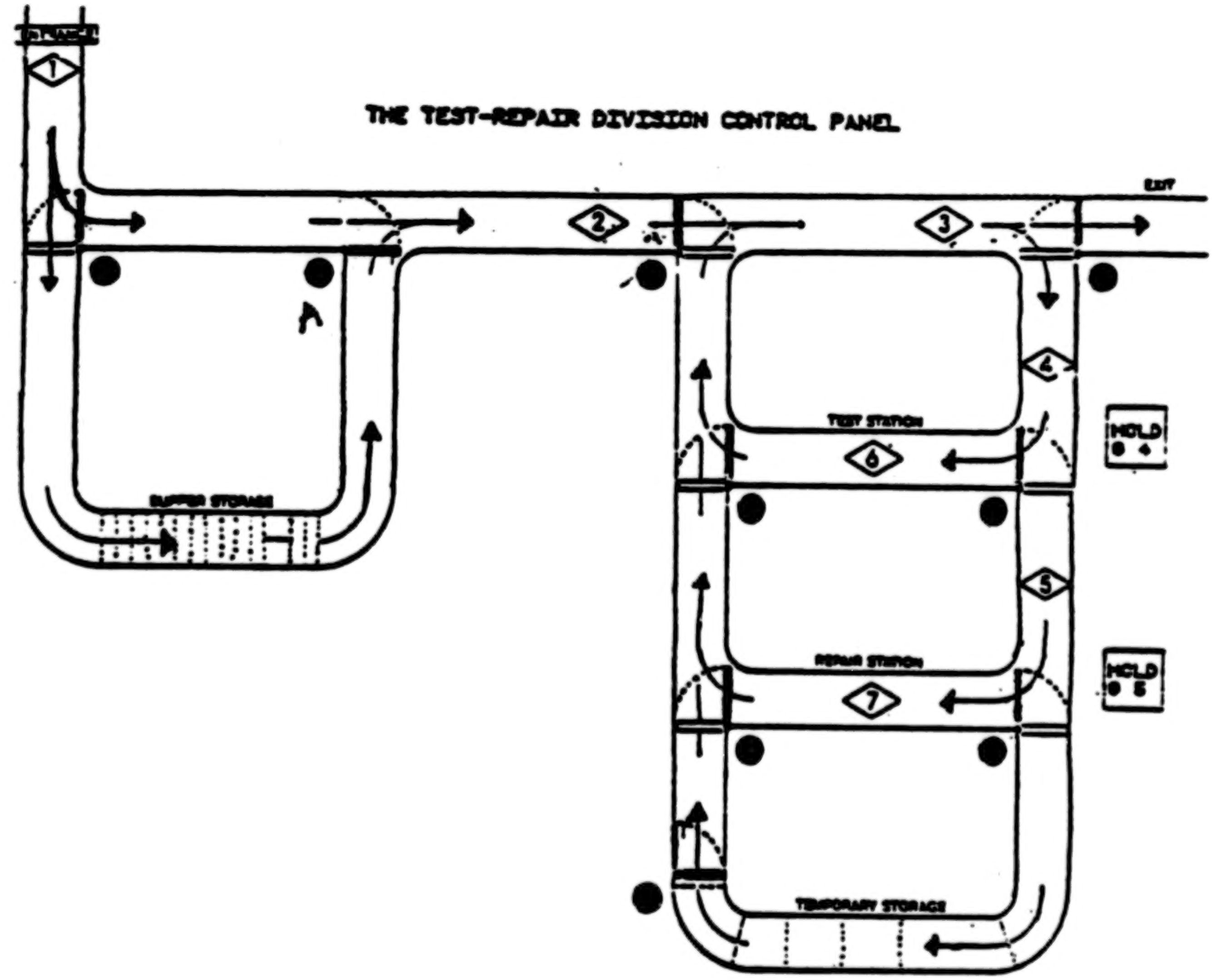

ENTRANCE
1
THE TEST-REPAIR DIVISION CONTROL PANEL
EXIT
2
3
4
BUFFER STORAGE
TEST STATION
6
HOLD # 4
5
REPAIR STATION
7
HOLD # 5
TEMPORARY STORAGE

FIGURE 7

engine at a station or on a conveyor belt at any given time.

Figure 8 contains an information display for this system. This display might correspond to a traditional hardwired display or to a fairly primitive CRT display in which there was no attempt to exploit the capabilities of the computer-driven display.

In trying to create displays that were more attuned to the human's information needs, a modelling methodology was used to structure information needs by control functions. Individual control activities were grouped together into meaningful control functions with a strategy that might be similar to the way in which a controller thinks about them. Next, information needed to evaluate the feasibility of actions for particular control functions was identified, examined, and structured.

An example may help to illustrate the point. Entry control is a vital control function in the system. It concerns routing engines from the Buffer portion of the system to the Test-Repair loop. Poor entry control strategy will result in poor overall system performance. The fundamental entry control decision is whether or not to release an engine waiting at Station 2 into the Test-Repair loop. Given the system constraints, in order to release an engine, a number of conditions must be met: an engine must be waiting on Station 2; Stations 3 and 4 must both be clear, and both the Test-Repair Feed and Test-Repair Exit conveyors must be clear. There is a natural structure and hierarchy to these conditions which is represented in Figure 9. The presence or absence of an engine at Station 2 is of primary importance. One can not route an engine which is not there. Given the presence of an engine at the Station, the status of the other related system components must be examined. The rules of the system constrain the operator so that an engine may be released from Station 2 only if each of the other four components is in a clear or idle state. Thus, at one level all the controller is concerned about is whether or not these four components are in the required configuration. This suggests that a higher level information system might be appropriate, one that summarizes the respective statuses of these components and

TEST-REPAIR DIVISION INFORMATION SYSTEMS

EXPEDITE: TYPE 1 ENGINES

STATION 1: CLEAR

STATION 2: TYPE 1 ENGINE

STATION 3: CLEAR

STATION 4: ENGINE HELD (1,T)

STATION 5: ENGINE HELD (2,R)

STATION 6: BUSY(TYPE 1)

STATION 7: LOCKED(1,C)

PRODUCTION BUFFER TRACK: CLEAR

TEST-REPAIR FEED TRACK: CLEAR

TEST-REPAIR EXIT TRACK: CLEAR

HOLD AT 4: ON

HOLD AT 5: ON

TEMPORARY STORAGE LOCK: OFF

BUFFER STORAGE: 1,2,2,2,1,1,2,2,2,2,2,2

TEMPORARY STORAGE: (1,C),(1,R),(1,C),(1,C)

SWITCH 1: CLOSED TO STATION 2

FIGURE 8

ENTRY CONTROL INFORMATION

INPUTS: STATION 2, TEST-REPAIR FEED TRACK, TEST-REPAIR EXIT TRACK, STATION 4, STATION 3.

STATES: ENTER, STANDBY

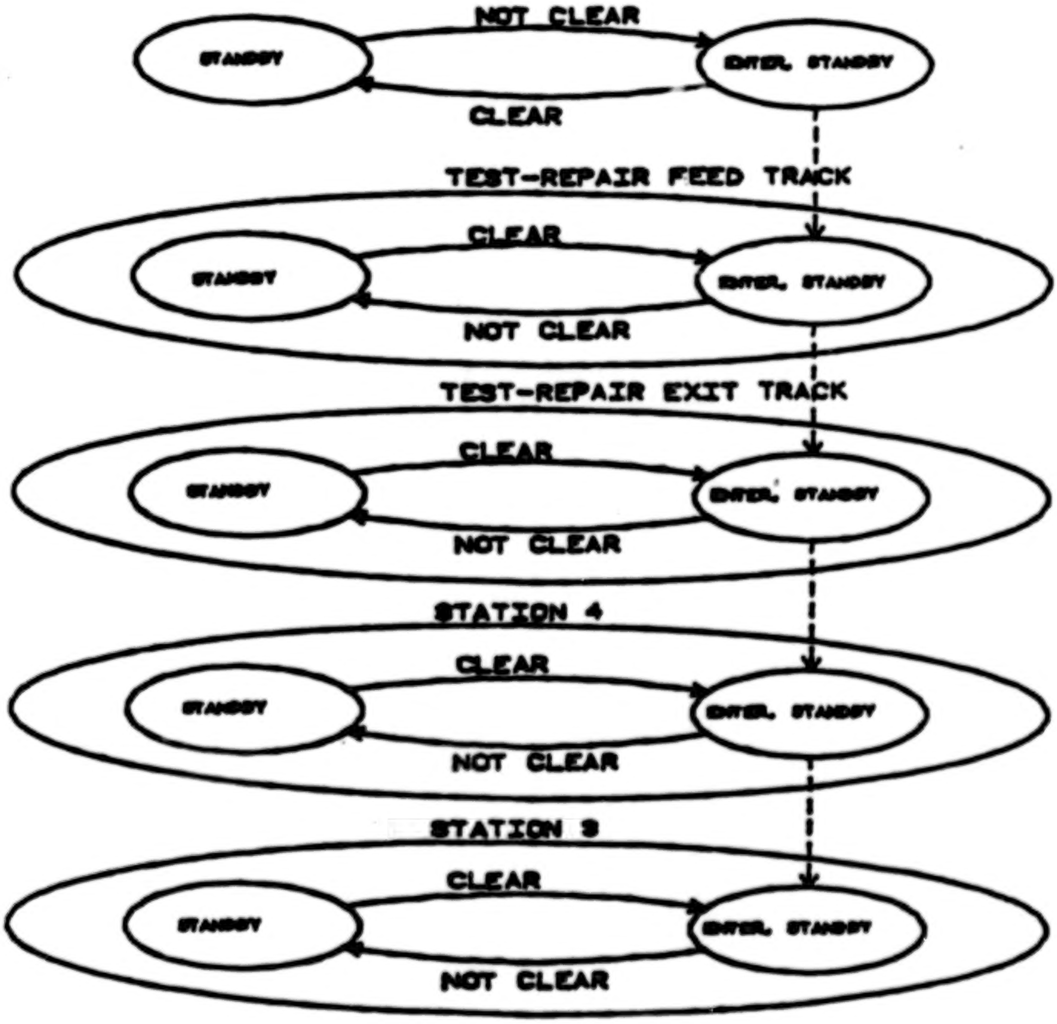

NOT CLEAR
STANDBY
ENTER, STANDBY
CLEAR
TEST-REPAIR FEED TRACK
CLEAR
STANDBY
ENTER, STANDBY
NOT CLEAR
TEST-REPAIR EXIT TRACK
CLEAR
STANDBY
ENTER, STANDBY
NOT CLEAR
STATION 4
CLEAR
STANDBY
ENTER, STANDBY
NOT CLEAR
STATION 3
CLEAR
STANDBY
ENTER, STANDBY
NOT CLEAR

FIGURE 9

presents it in a form compatible with the human's model of the system. Figure 10 depicts this situation by means of the Test-Repair Feed System. This system is, in fact, not a system component at all - it is a pseudo-component, an artifact developed to enhance the human-computer dialogue. This system is in the available state only when the four real system components it summarizes are in the appropriate states for an Entry control action, i.e., all available. Otherwise, the Test-Repair Feed System is unavailable.

Figures 11 and 12 depict displayed information in response to an operator's request for Entry control information. Figure 11 gives the status of Station 2 but indicates that the Test-Repair Feed System is not in an appropriate state for Entry control activity.

Figure 12 illustrates another aspect of the information display system. In this case, there is no engine at Station 2; thus, regardless of the state of the other system components, an Entry control action can not be undertaken. As a result, the state of Station 2 is all the information that is displayed. The empty status of Station 2 is a sufficient condition for terminating further consideration of a control action at that point. This type of selective display of information is an attempt to match the processing strategy of an operator and to reduce cognitive load by dynamically limiting and filtering displayed information. If the controller desired to see the more detailed status of the individual system components, he could summon that information (Figure 13). This figure depicts the status of all the system components potentially affecting an Entry control decision.

As a third option, the controller could request to see all the information, unorganized and unfiltered. This display is given in Figure 8. It is interesting to note that controllers who had access to these three levels of displays rarely took advantage of the lower level displays, preferring the aggregated, summarized, and filtered displays.

This method of information display assumes that systems and information about systems can be structured in a hierarchic form. For a supervisory or monitoring role, the

ENTRY CONTROL INFORMATION

INPUTS: STATION 2, TEST-REPAIR FEED SYSTEM.

STATES: ENTER, STANDBY

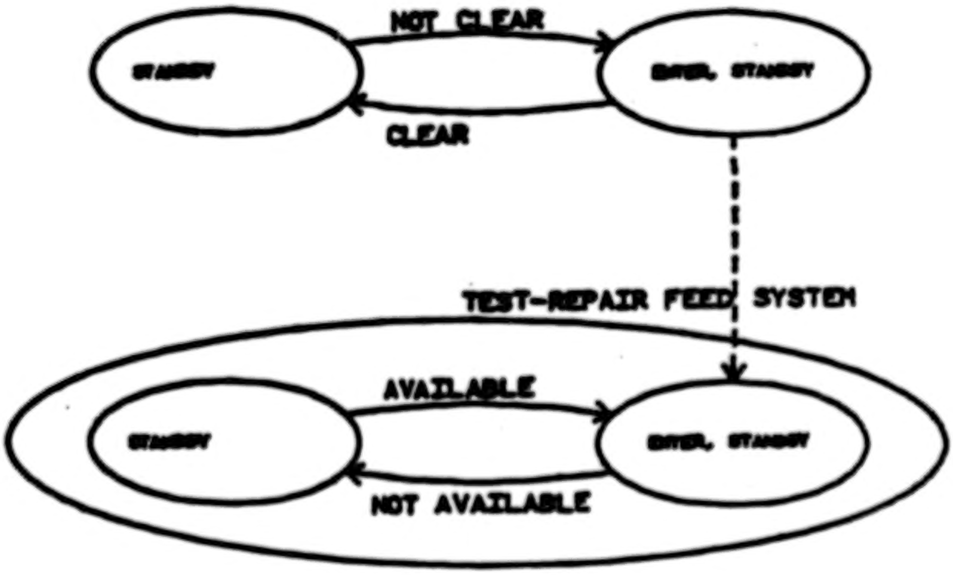
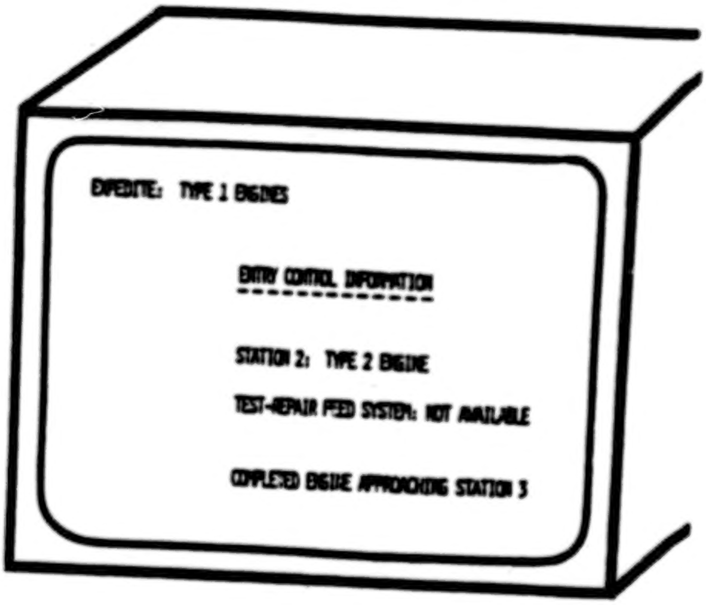

NOT CLEAR
STANDBY
ENTER, STANDBY
CLEAR
TEST-REPAIR FEED SYSTEM
AVAILABLE
STANDBY
ENTER, STANDBY
NOT AVAILABLE

FIGURE 10

HIERARCHIC INTEGRATED INFORMATION DISPLAY



EXPEDITE: TYPE 1 ENGINES

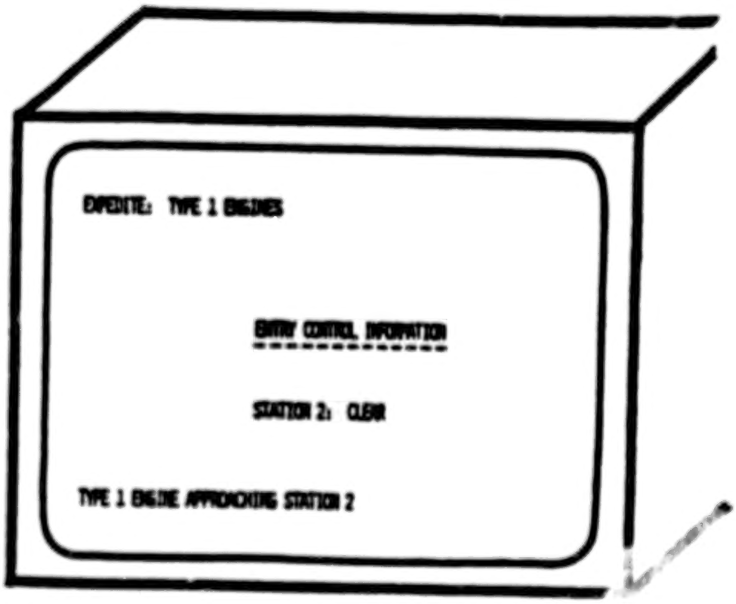
ENTRY CONTROL INFORMATION

STATION 2: TYPE 2 ENGINE

TEST-REPAIR FEED SYSTEM: NOT AVAILABLE

COMPLETED ENGINE APPROACHING STATION 3

FIGURE 11



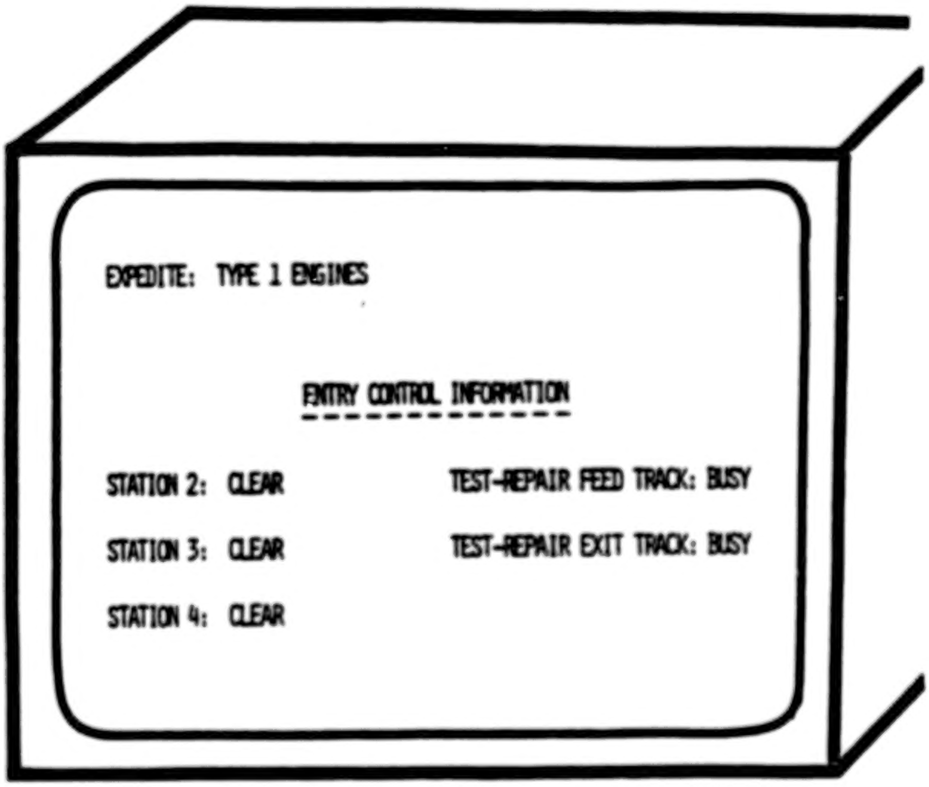
EXPEDITE: TYPE 1 ENGINES

ENTRY CONTROL INFORMATION

STATION 2: CLEAR

TYPE 1 ENGINE APPROACHING STATION 2

FIGURE 12



EXPEDITE: TYPE 1 ENGINES

ENTRY CONTROL INFORMATION

STATION 2: CLEAR
TEST-REPAIR FEED TRACK: BUSY
STATION 3: CLEAR
TEST-REPAIR EXIT TRACK: BUSY
STATION 4: CLEAR

GROUPED PRIMITIVE INFORMATION DISPLAY—CONDITION 2
ENTRY CONTROL INFORMATION

FIGURE 13

human controller views the system at the higher levels or possibly drops down one or two levels, viewing the systems as a collection of hierarchical subsystems. The switch to a manual mode requires that the controller descend down the hierarchy viewing the system at lower and more detailed levels, likely requiring lower and more detailed information. This notion of hierarchic structure is compatible with much of the system approach to design as well as models of human cognition. The problem, of course, is that displays of this type are not easy to design; the computer is a new display medium, and there is no prior experience.

Summary and Conclusions

This hierarchical approach to information display has several advantages. It explicitly forces the system designers to develop a set of (human-oriented) system models which will guide the design of the displays. If the displays are designed around the operator's decision making needs, they are likely to become more human-oriented and less hardware-oriented. If the appropriate information is provided at the appropriate time, it is likely that less information will be displayed at any given time, and the quality of the displayed information will require less operator effort to integrate into an assimilatable form. A very pressing problem with contemporary control rooms is that there is just too much information for an operator to be able to assimilate quickly, easily, and accurately. Humans are easily overloaded, particularly by the displays of great amounts of irrelevant information (Ackoff, 1967; Seminara et al., 1979). Moreover, human ability to integrate multiple pieces of displayed data into meaningful information is very limited (Rouse, 1973; 1974; 1975). As a result, a reasonable and perhaps vitally necessary direction for research in the area of automated control room design is to develop displays which provide active decision aiding for the modern controller. What is needed are displays which provide information compatible with the operator's current internal model, filter out irrelevant information, and summarize and condense lower level information so as to be in a form suitable for the operator's high level information needs.

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SUMMARY OF WORKSHOP INTERACTION

Human as Supervisor in Automated Systems

This workshop traced the role of humans in the control of systems. Concern was voiced that automation would eliminate jobs. Automation might entail retraining but not necessarily elimination of jobs.

A question was raised whether computers control people or whether the operator is given enough information to make decisions. There was an exchange of ideas concerning the amount of information to be presented to the operator. How much is necessary to make error-free decisions? Should the information then be arranged hierarchically? Does the human monitor procedure? One approach is monitoring by exception. NRC is an example of this type of monitoring. The discussion among the attendees supported the view that it would be desirable to have summarized displays with the option of calling up more detailed information if desired. Dr. Mitchell's current research interests analyze these types of hierarchical displays. Another question raised the issue of the extent to which the computer can be trusted to carry out specified tasks. The subsequent discussion centered on the desirability of increased automation; the desired level of increased automation is a subject of current research.

ERBS
HUMAN FACTORS ANALYSIS: A CASE STUDY

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ERBS HUMAN FACTORS ANALYSIS: A CASE STUDY

How can human factors be incorporated into the system development process at Goddard Space Flight Center (GSFC), and what benefits can be derived? These questions provided the motivation for a case study discussion in the workshop sessions. The human factors analysis task for the Earth Radiation Budget Satellite (ERBS) Payload Operations Control Center (POCC) serves as a pathfinder in the new applications approach to this discipline within the Mission and Data Operations Directorate. The topics covered in this report include discussions of the motivation for human factors analysis, the involvement of the Human Factors Research Group (HFRG) with project and system developers, and some examples of human factors issues being addressed in the ERBS analysis task.

Although Human Factors has been a recognized discipline for decades, only recently has the computing community paid attention to what insights it might offer for improved systems. New technology is rapidly evolving in devices and methods for human interaction with data systems. We cannot ignore the trends to use color or voice or decision support systems for very long. Some new tools quickly become burdensome if misused, so we must become informed and use them appropriately. Since labor costs are the biggest cost drivers in system operations at GSFC, the correct application of human factors principles will optimize the role of the human in the data system. By reducing display ambiguity, reducing fatigue factors and removing system deficiencies which are typically compensated by greater human effort, we can reduce the chance of human error and improve human and therefore, total system efficiency.

The next question to address is how to establish a human factors task. In the case study, the ERBS project requested that greater attention be placed on the human interfaces for the new systems being developed for the ERBS POCC. Most notably, the command panel and the color display monitors were planned to include new features for ERBS. The HFRG responded by establishing its first applications group. Its success relies on an integrated team approach: project managers, who represent the scientists and define requirements, and system engineers, who build the system tools, work with the human factors analysis to optimize the human's role in the operations of the system. Figure 1 depicts the team defined for the ERBS human factors task. Three key roles have been identified—the task coordinator, the human factors analyst, and the mission specialist. The coordinator manages the human factors task by identifying plans, schedules and budgets. The human factors analyst is cognizant of key human factors concerns and trained to identify potential problem areas. In order to be effective, the human factors task must be specifically oriented to the particular mission under analysis. The mission analyst provides the critical link with the facility or project and is the source for interpreting user requirements. In the case of ERBS, this position can be fulfilled from either the POCC development team or the project operations team. The human factors analyst may likely be a graduate student in a human factors related field from a supporting university.

ERBS HUMAN FACTORS CADRE

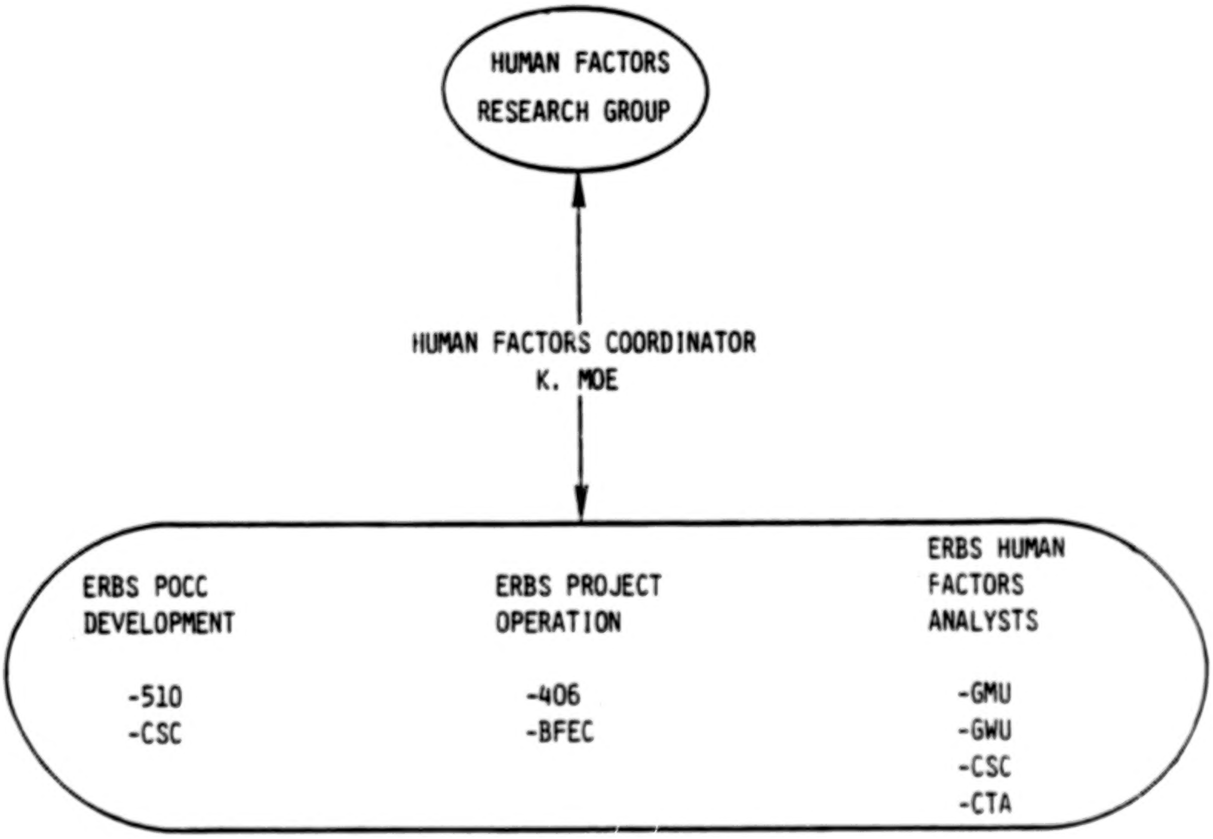
HUMAN FACTORS
RESEARCH GROUP
HUMAN FACTORS COORDINATOR
K. MOE
ERBS POCC
DEVELOPMENT
-510
-CSC
ERBS PROJECT
OPERATION
-406
-BFEC
ERBS HUMAN
FACTORS
ANALYSTS
-GMU
-GWU
-CSC
-CTA

Figure 1

The task flow for an applied human factors analysis is depicted in figure 2. The task begins with a determination of human factors requirements and drivers in operations. The HFRG plans to develop guidelines for analyzing the human role in systems developed at GSFC. An operations scenario provides a detailed synopsis of all operator activities during a critical time period. In the case of ERBS operations, a minute-by-minute rundown of Mission Operations Room (MOR) activities during a typical 30 minute satellite pass was generated.

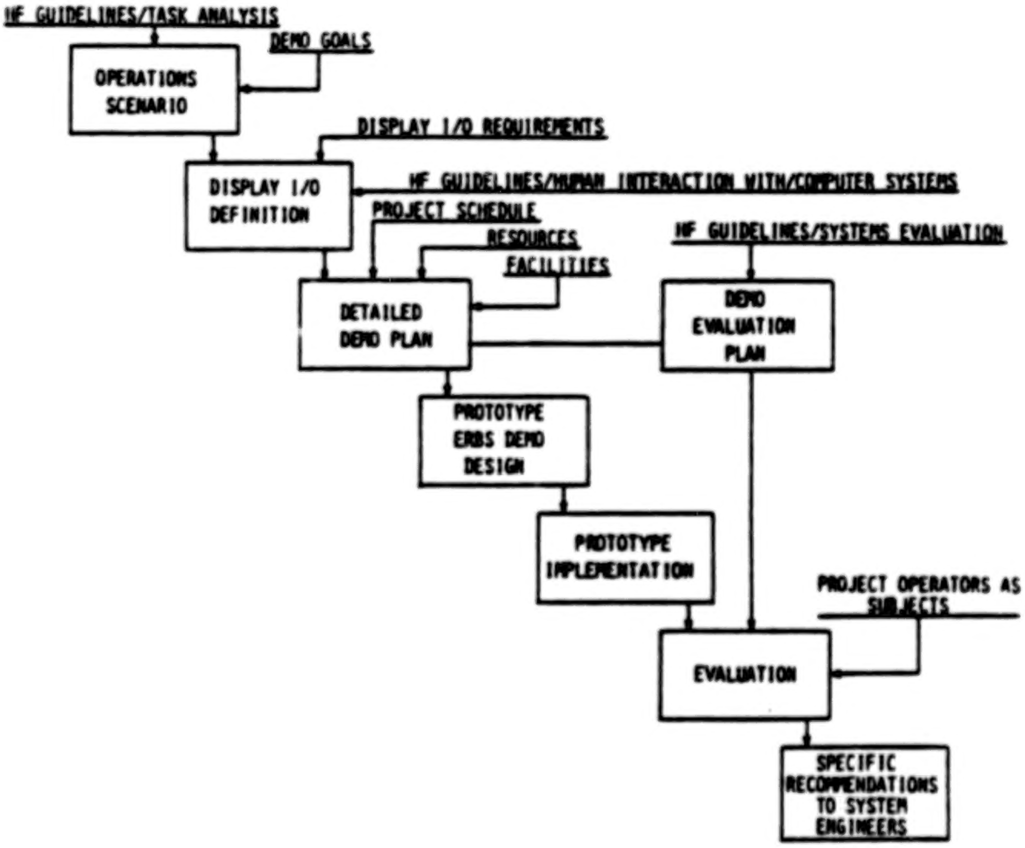
HF GUIDELINES/TASK ANALYSIS
DEMO GOALS
OPERATIONS SCENARIO
DISPLAY I/O REQUIREMENTS
DISPLAY I/O DEFINITION
HF GUIDELINES/HUMAN INTERACTION WITH/COMPUTER SYSTEMS
PROJECT SCHEDULE
RESOURCES
FACILITIES
HF GUIDELINES/SYSTEMS EVALUATION
DETAILED DEMO PLAN
DEMO EVALUATION PLAN
PROTOTYPE ERBS DEMO DESIGN
PROTOTYPE IMPLEMENTATION
PROJECT OPERATORS AS SUBJECTS
EVALUATION
SPECIFIC RECOMMENDATIONS TO SYSTEM ENGINEERS

Figure 2

The human factors task analysis includes a methodical description of what the human does in both routine and simple contingency situations. It provides a behavioral basis for design requirements and evaluations, in addition to assuring that the performance of tasks is within human capabilities and minimizes errors. A link analysis is then used to ensure an efficient display layout. A link analysis is a structured exercise to collect, organize and interpret display data by examining the links between two entities on a display and determining the optimal layout. Future guidelines will be generated to specifically address human/machine interaction alternatives, including the pros and cons of new technologies in interface devices and system design concepts.

The link analysis will result in a set of candidate desplays. The human factors analyst will design an experiment to assess the utility of the candidate displays in a prototype test environment. The design will define tasks and measures of performance while limiting the number of experimental factors. ERBS system data will be simulated and run in conjunction with the candidate displays within the experimental design framework. A formal experiment will then be conducted and data collected to evaluate the candidate displays. Statistical analysis on the experimental data will be analyzed and conclusions drawn.

This analysis approach will allow the ERBS human factors cadre to actually see and evaluate prototype displays without having to implement them in the POCC software. The HFRG plans to generalize this prototyping capability to provide an analysis tool for future applications.

An analysis or demonstration plan will be generated for each human factors task, taking into account the system development schedule, facilities and resources available for the analysis. Figures 3 and 4 outline the goals and approach for the ERBS demonstration plan. Specific human factors drivers were identified as the command panel interface design, the use of color and graphic displays, combining graphics and alphanumerics on one display, the decision support features of the spacecraft telemetry monitoring pages, and the MOR workstation design. With a Shuttle launch scheduled in the summer of 1984, a one year effort for the ERBS human factors task is planned with intermediate results and recommendations scheduled to coincide with ERBS design reviews.

ERBS HUMAN FACTORS DEMONSTRATION PLAN

- GOALS:

  INCREASED SAFETY AND EFFICIENCY IN CONTROL CENTER OPERATIONS

- SPECIFIC OBJECTIVES:

  ANALYZE AND DEMONSTRATE THE IMPACT OF HUMAN FACTORS CONCEPTS IN THE FOLLOWING ERBS CONTROL CENTER FUNCTIONS:

  1. SPACECRAFT COMMANDING
  2. CONTROL CENTER DISPLAYS

  MAKE SPECIFIC RECOMMENDATIONS REGARDING HUMAN FACTORS ISSUES IN THE DESIGN OF ABOVE FUNCTIONAL AREA

Figure 3

STEP 1. PERFORM COMPREHENSIVE TASK ANALYSIS

- DETERMINE S/C COMMANDER'S ROLE DURING S/C CONTACT

STEP 2. DEVELOP A SPECTRUM OF HUMAN ENGINEERED COMMAND PANEL LAYOUTS

STEP 3. DEVELOP A PILOT DEMONSTRATION SYSTEM, SELECTING LIKELY COMMAND PANEL CANDIDATES FOR USE IN EXPERIMENTAL EVALUATION

- EXPERIMENTAL DISPLAY PROTOTYPING SYSTEM
- SIMULATED ERBS MOR ELEMENTS

STEP 4. RUN A CONTROLLED EXPERIMENT USING ERBS CONTROLLERS

STEP 5. PERFORM HUMAN FACTORS ANALYSIS, MAKE RECOMMENDATIONS

Figure 4

Our brief experience with human factors analysis for ERBS has surfaced three potential problem areas. Timing is the first critical issue. If the HFRG is requested to analyze human factors late in the system development cycle, say during the critical design review, then the analysis may be reduced to a general critique of stated requirements, without full appreciation of the operational philosophy. The task and link analysis for the ERBS project is expected to take two to three months, so the resultant recommendations will go well beyond the surface analysis that a set of guidelines can address. The explicit definition of the planned actions of the operator is the key difference in these two approaches.

The second problem area involves the interaction of system engineering concerns (system architecture, computer sizing, etc.) with human factors issues as described earlier. Past experience has indicated that many human factors issues have been inadequately addressed. The goal of applied human factors is to insure that it becomes an important element in systems engineering when design trade-offs are evaluated.

The final area is one that affects the entire system development cycle and makes systems engineering so challenging—requirements definition. As people's view or conceptual model of the system evolves with new understanding, or sometimes with erroneous assumptions, the requirements change. Although human factors analysis will not solve this problem, it should prove to be extremely valuable in illuminating the critical requirements involving the human interface.

The second portion of the workshop session was presented by Chuck Weger of Computer Sciences Corporation. He provided a brief overview of the initial discussions of the ERBS command panel. The advantages and limitations of the CRT panel layout (format, resolution, color, etc.) and alternative input devices (touch panel, light pen, mouse, etc.) have been discussed by the HFRG with ERBS operations. Figure 5 shows the proposed layout for the touch terminal display from the command panel requirements document. The hardware was defined to include a color raster CRT display, touch panel input system, color hardcopy device and microprocessor controller. The two candidate terminals selected by the POCC, the Intelligent Systems Corporation ISC-8000 and the Industrial Data Terminal IDT-2000, augmented with a CDP F-64 microprocessor are compared in figure 6. The low resolution ISC was demonstrated and found to be inadequate for displaying the entire proposed panel layout due to distortion on the curved screen edges and limited character sizes. Although somewhat over specified for the command panel job as proposed, the medium resolution IDT-2000 was recommended over the ISC-8000.

TOUCH TERMINAL DISPLAY

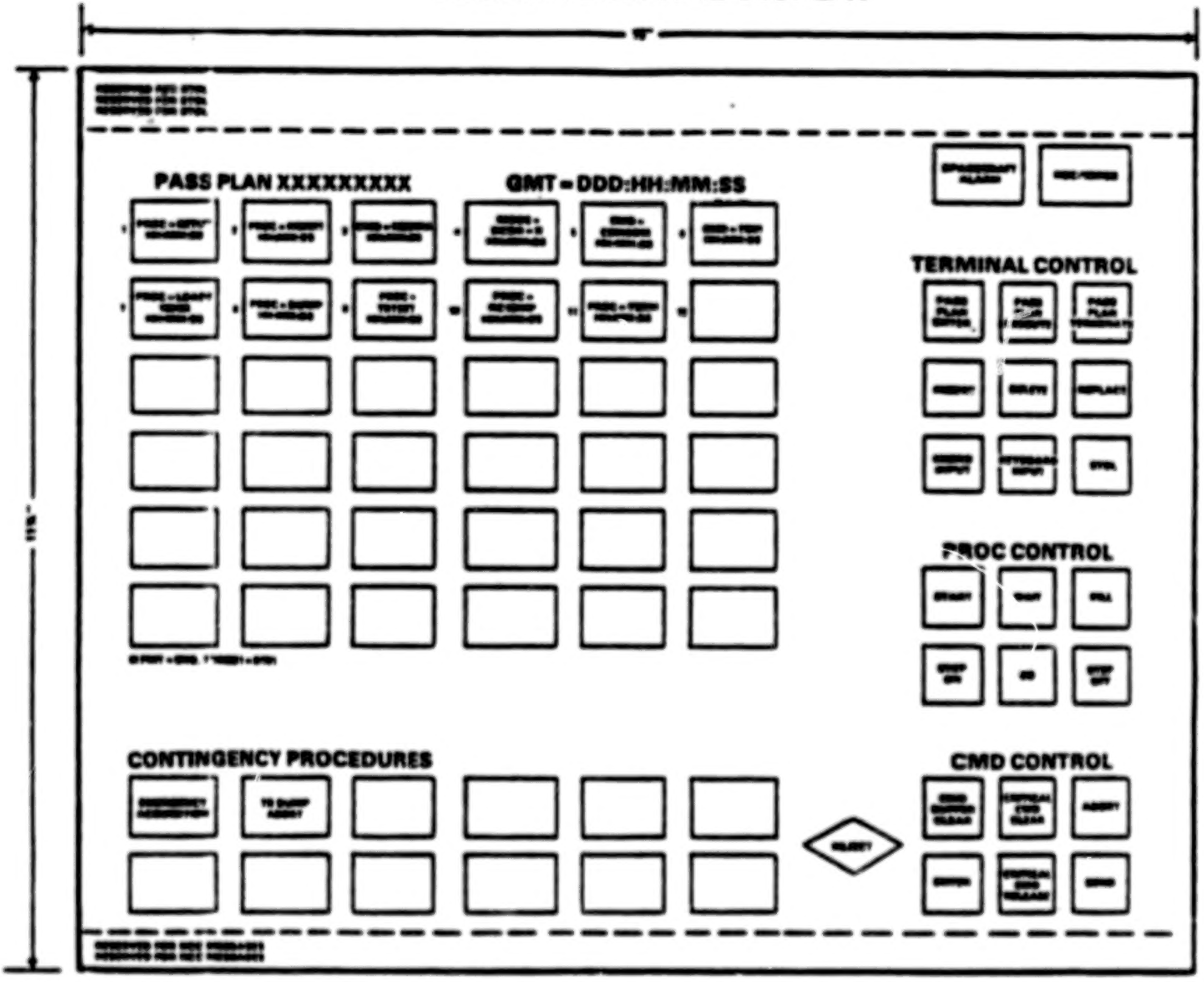
PASS PLAN XXXXXXXXX
GMT = DDD:HH:MM:SS
TERMINAL CONTROL
PROC CONTROL
CONTINGENCY PROCEDURES
CMD CONTROL

Figure 5

TYPICAL DISPLAY CHARACTERISTICS

	ISC 8000 SERIES	IDT 2000 SERIES
IMAGE SIZE	160H × 192 V	512 H × 512 V
NUMBER OF COLORS	8	8
CHARACTER CAPABILITY	80 COLUMNS × 48 LINES	85 COLUMNS × 51 LINES
MONITOR SIZE (DIAGONAL)	19"	19"
VECTORS	NO	YES
POLYGON FILL	NO	YES
LOCAL IMAGE BUFFER	NO	YES

Figure 6

Traditionally, GSFC MOR's are equiped with alphanumeric, black and white displays for several reasons including low cost, simplicity of software design, well-known and easily managed device technology, and fulfillment of basic requirements for the job. As the color CRT market has been evolving, GSFC system designers are turning to color. Color is a more natural medium to the human eyes and offers the potential for increasing the information content of displays. Also color costs are dropping dramatically and more people are becoming aware of computer color capabilities. Not surprisingly, color has both advantages and disadvantages to offer the systems designer. Careful use of color is capable of providing information which is more readily and easily assimilated, and could potentially increase productivity. Furthermore color allows effective segmenting of display space, much more so than foreground-background video techniques. In the GSFC POCC however these advantages are offset by the cost to upgrade and overcome incompatabilities with existing facilites . Also there is the danger of producing flashy or busy displays which reduce, rather than increase, productivity and efficiency. As was graphically illustrated in the concluding video tape entitled "Graphic Harmony -Conversations on Color and Computer Graphics" (written, directed and produced for Polaroid by J. Ruddy) appropriate use of color is a positive enhancement to the human/machine interface.

MECHANICS OF CONDUCTING A TASK ANALYSIS

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MECHANICS OF CONDUCTING A TASK ANALYSIS

Task analysis (TA) is a set of analytical procedures used to describe human work in terms of tasks. The method of TA was derived from various techniques of methods analysis of the industrial engineers. It is also commonly referred to as an activity analysis (McCormick, 1979).

For purposes of this discussion, the topic of TA is organized around the following main areas. The first area centers around a more detailed discussion of what a TA is. The second area focuses on the uses of TA. Next, the benefits of TA to Goddard systems will be addressed. Finally, evaluation of the TA procedure and an assessment of the procedure's worth will be discussed.

In order to understand exactly what a TA is, one has to first understand what is meant by a task. Webster defines a task as an assigned piece of work often to be finished within a certain time. McCormick (1979) lists six characteristics of a task that offer a more detailed description of a task (fig. 1). For instance, take the example of driving a car. The activities associated with the car's locomotion are independent (e.g., steering is separate from shifting), but they are also related in that all activities collectively move the vehicle. Driving the car starts with the insertion of the ignition key and definitely ends with removal of that same key. One certainly interacts with the car and its parts, and of course the driver interacts with other people on the highway (sometimes to his dismay). Certain people would contend that driving a car is meaningful, it can be enjoyable, not to mention it gets you where you want to go faster than walking. Driving does indeed involve a mixture of complex decisions such as steering the car to avoid a pothole. Driving also involves perception and motor activities in that you perceive some sort of motion and use motor skills when driving. Although driving a car is not as complex as piloting a Concorde, it is more complex than brushing one's teeth. Thus, tasks vary in their complexity. If, for

FIGURE 1

TASK ANALYSIS IS AN ANALYTIC PROCEDURE FOR USE IN DESCRIBING HUMAN WORK IN TERMS OF TASKS (McCORMICK, 1979)

A TASK:

- IS A GROUP OF INDEPENDENT BUT RELATED ACTIVITIES DIRECTED TOWARDS A GOAL
- USUALLY HAS A BEGINNING AND AN END
- INVOLVES PEOPLE'S INTERACTION WITH EQUIPMENT (INCLUDING COMPUTERS), OTHER PEOPLE, AND/OR THE MEDIA
- WHEN PERFORMED RESULTS IN A MEANINGFUL PRODUCT (I.E., CORRECT DECISION)
- INCLUDES A MIXTURE OF DECISIONS, PERCEPTIONS, AND/OR PHYSICAL (MOTOR) ACTIVITIES REQUIRED OF ONE PERSON
- MAY BE OF ANY SIZE OR DEGREE OF COMPLEXITY, BUT IT MUST BE DIRECTED TOWARD A SPECIFIC PURPOSE OR SEPARATE PORTION OF THE TOTAL DUTY

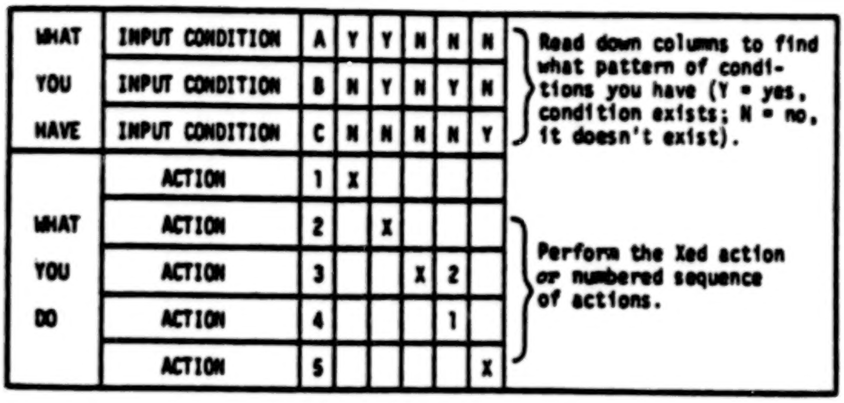
example, the analysis of such complex tasks as flying a jet or analyzing a vast computer network (like many Goddard systems) was to be performed, then the best procedure would be to break down the task's analysis into sub-tasks and analyze them as such. When doing sub-task analyses on a complex task, caution must be observed. Sub-task analyses can often overshadow the concept of the whole task, causing an experimenter to lose sight of the sub-tasks as a subset of the major task.

Over the course of the last few decades, experimentation with task analysis (TA) has yielded many types of analysis techniques. Some of the techniques are individually tailored to their tasks, while others are general enough to be used in a variety of tasks. The first TA technique is referred to as a Decision table (fig. 2). This technique utilizes tasks which involve complex decision making or problem solving. The decision table method sets forth various possible input conditions and specifies the action that should be taken in each combination of input conditions (McCormick, 1979). For example, the three input conditions in figure 2 could be three different types of information from a computer panel from which various decisions have to be made in order to respond accordingly. Figure 3 represents a Decision Flow Chart. This technique is an elaboration of the decision table except that it is more specifically applicable to circumstances which involve a series of alternate action paths. It also involves a yes-no decision which is to be made at several condition points to be followed by various response actions (McCormick, 1979). The decision flow chart is very similar to a branching model style used by computer specialists, and flow charts are used in business and other areas as well.

The next type is the Outline format (fig. 4). An outline format is good to use in cases where continuous activities are performed. It provides for analyses of discriminations (like input from some source), decision, action responses, indications of response adequacy, and indications of characteristic errors (McCormick, 1979). Figure 4 contains a good example of using

FIGURE 2

Hypothetical example of a decision table. (Source: *Handbook for Designers of Instructional Systems*, p. 2-25)

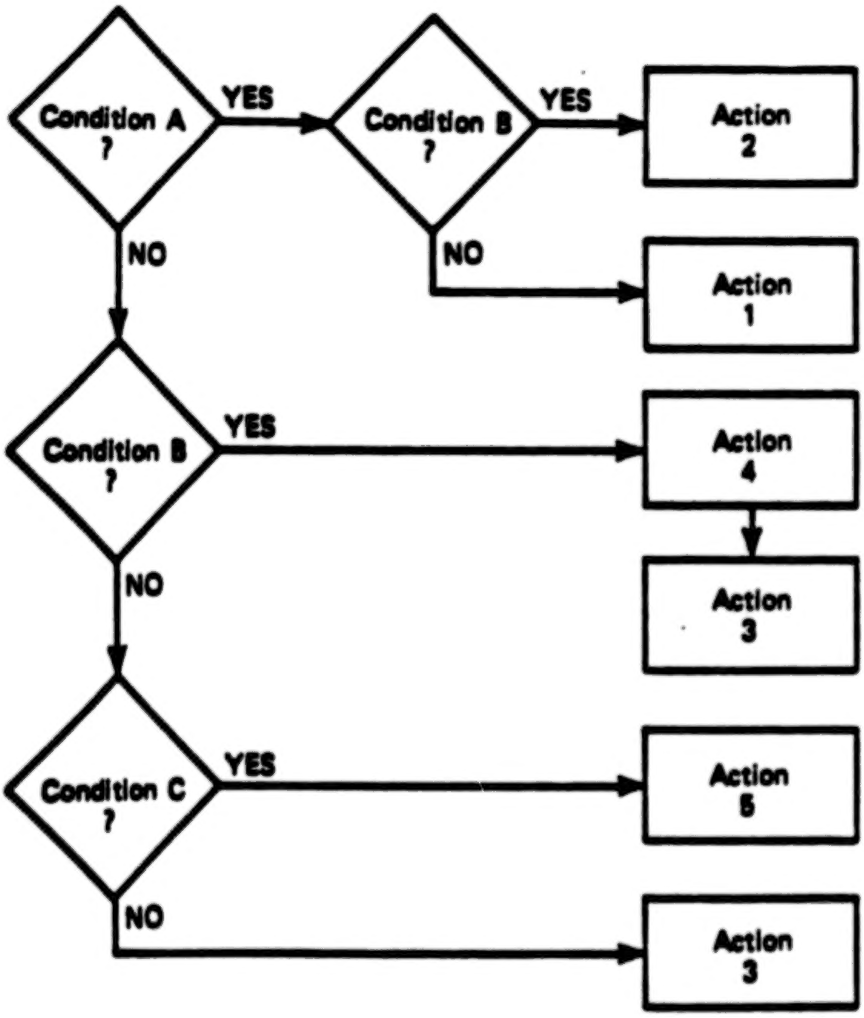


WHAT	INPUT CONDITION	A	Y	Y	N	N	N
YOU	INPUT CONDITION	B	N	Y	N	Y	N
HAVE	INPUT CONDITION	C	N	N	N	N	Y
	ACTION	1	X				
WHAT	ACTION	2		X			
YOU	ACTION	3			X	2	
DO	ACTION	4				1	
	ACTION	5					X

Read down columns to find what pattern of conditions you have (Y = yes, condition exists; N = no, it doesn't exist).

Perform the Xed action or numbered sequence of actions.

FIGURE 3


Condition A
?
YES
Condition B
?
YES
Action
2
NO
NO
Action
1
Condition B
?
YES
Action
4
NO
Action
3
Condition C
?
YES
Action
5
NO
Action
3

Generalized illustration of a decision flowchart. (Source: *Handbook for Designers of Instructional Systems*, p. 2-26)

FIGURE 4

Example of an outline format used in analysis of the task of passing in driving an automobile. (Source: *Handbook for Designers of Instructional Systems*, p. 2-28)

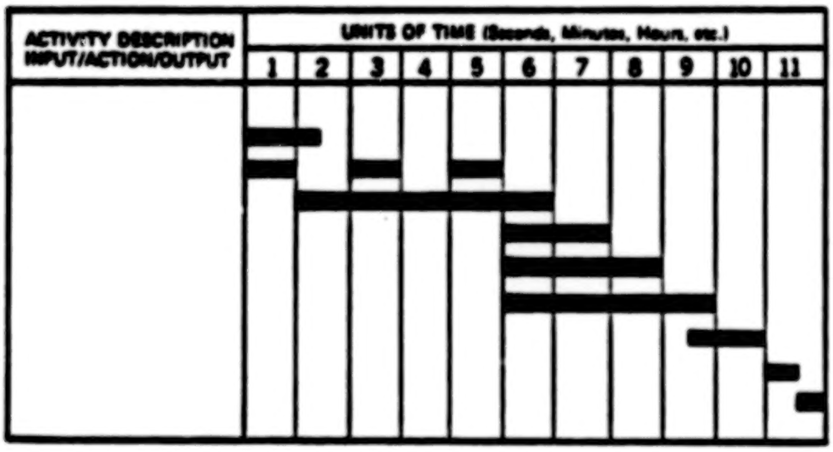
I	**INPUTS (Cues)**	Your car (O) is in act of passing car X. Oncoming car Y appears ahead. Car X is to the right and ahead. Assume competing car will not accelerate.	
	Problem—Critical Cue Variables	1. The absolute rate of car being passed (X). 2. The absolute rate of oncoming car (Y); cars of variable size and speed. 3. The absolute momentary distance between X and Y. 4. The acceleration potential of car O at that speed (knowledge requirement).	
	Time Values	Critical, since a time of no return will be reached when it is too late to either dive in front of X or to brake. Time is function of 1, 2, 3, and 4 above.	
	Noise	1. Stress may occur. 2. Worry that X will increase speed while passing.	
II	**DECISIONS**	Pass now or pass later.	
III	**ACTIONS**		
	Item Acted Upon	Accelerator	Steering Wheel
	Specific Action	For rapid access of power, press all the way to floor board past a resistance detent.	
	Effect of Action	Downshifts transmission from 3rd to 2nd gear (if below 50-55 mph). More power from faster engine-to-wheel ratio.	
IV	**INDICATIONS OF CORRECT ACTION**		
	Outputs	Same as inputs, but as X, Y, and O converge, the success or failure of the action becomes more apparent.	
	Time Delay	Function of acceleration rate of car.	
	Criterion of Correct Action	Getting back into right lane with "safety margin" (50 ft. plus, depending on speed). (Better criterion would be in terms of time between turning in to right lane and potential collision: 5 sec.)	
	Critical Value	Collision course perceived imminent.	
	Corrective Action	Brake and return to right lane or head for ditch on left.	
V	**CHARACTERISTIC ERRORS**	Misjudges one or more of critical cue variables; hesitates in application of accelerator.	

the outline format in the examination of passing another car when driving on the highway.

The last example of a TA technique is the time-line format (fig. 5). This technique is useful for showing various activities along a time scale or how different activities are carried out over time. Time-line formats are useful for tasks in which the sequence and time of performed activities is critical. The activities represented would be input, action, and output functions expressed in terms of hours, days, minutes, milliseconds, etc. (McCormick, 1979). This tool is useful in planning events like critical path analyses, evaluation of milestones, and to show various overlapping tasks. Figure 6 represents a summary chart for task types and the technique which best describes or characterizes those tasks. Complex decisions or problem solving such as a Goddard real-time system which requires monitoring of incoming data and problem solving are best described in the Decision Table/Flow Chart, or The Outline Format. Continuous activities and activities performed in sequence like the previous example of driving a car are best described in the Outline format or Time-line format. Step-by-step activities and identifiable procedures such as the highly documented functions required during a routine satellite pass would best be described in a column format.

In summary, description of a task and a TA have been presented, along with the types and techniques of TA. The next, logical step is to describe some of the uses of TA. In the past, the principal use of TA was by the military in the development of new systems and in the evaluation of old systems. Figure 7 shows some of the current uses of TA. Most people in managerial positions should be familiar with many of these uses. Specifically, a TA used in a job redesign could provide insights on how to design the new job more efficiently than the previous job. TA can also provide a description of the current job that is more complete than a description found in a training manual. Personnel selection could benefit from TA as well. Knowing what the job entailed

FIGURE 5



Hypothetical illustration of a time-line format for use in task and activity analysis, showing overlapping of various activities. (Source: *Handbook for Designers of Instructional Systems*, p. 2-31)

FIGURE 6

GUIDELINES FOR SELECTING APPROPRIATE METHODS AND FORMATS FOR ANALYZING VARIOUS TYPES OF TASKS AND ACTIVITIES (HANDBOOK FOR DESIGNERS OF INSTRUCTIONAL SYSTEMS, PP. 2-24)

TASKS WHICH INVOLVE:	ARE BEST DESCRIBED IN:
- COMPLEX DECISION MAKING - PROBLEM SOLVING	DECISION TABLE/ FLOW CHART OR OUTLINE FORMAT
- CONTINUOUS ACTIVITIES - ACTIVITIES PERFORMED IN A SPECIFIC SEQUENCE, WITHIN A DEFINITE TIME FRAME	OUTLINE FORMAT OR TIME-LINE FORMAT
- STEP-BY-STEP ACTIVITIES - IDENTIFIABLE PROCEDURES	COLUMN FORMAT

FIGURE 7

WHAT ARE THE USES OF TASK ANALYSIS?

(McCORMICK, 1979)

TASK ANALYSIS IS USEFUL IN

1) JOB REDESIGN
2) DESCRIPTION OF EXISTING JOB
3) PERSONNEL SELECTION
4) TRAINING PROGRAM DEVELOPMENT
5) MANPOWER PLANNING, AND
6) EVALUATING MAN-COMPUTER INTERACTIONS AT GODDARD

would help to place personnel with certain skills in the right job. Also, TA can be used in manpower planning in that accurate descriptions could help to clarify where more or less people are needed in a system. The evaluation of man-computer interactions also involves TA. Adoption of a top-down methodology would require the TA as its first step in analyzing complex computer systems such as the systems found at Goddard. Many of Goddard's systems are carefully designed with respect to hardware and such, but so far there has been no evidence of the same rigorous approach applied to the design of the human end of the system. TA should be the first step in the understanding of how a person interacts with a computer system, and should yield hard data to aid in the analysis of such a system.

Each use of the aforementioned TA types as well as any other TAs should observe certain guidelines (fig. 8). Chapanis (1959) contends that it is important to establish rapport with employees, and also important to study the entire job. The categories of observation should be related to the purpose of the analysis, and should be exhaustive. Additionally, the activity should be defined clearly and represent observable behaviors. The data sheet itself should be complete and well-designed. Initial observations of the task or job should help decide what the sampling duration should be as well as assessing the sampling interval (if needed). When followed, these guidelines set forth by Chapanis (1959) lead to a more rigorous and useful tool.

The last section or main area to be discussed is whether or not TA is indeed the best technique to use in describing tasks. According to McCormick (1979), TA "represents an approach to job descriptions that is objective and perhaps quantitative" (p. 105). But is it a "good" tool? Well, TA is a valid tool; it has been in widespread use for several years with many researchers. TA is also a reliable tool because it measures objectively and as accurately as possible what it's supposed to measure. TA is versatile in that it can be applied to many

FIGURE 8

GUIDELINES FOR SETTING UP A TASK ANALYSIS

(CHAPANIS, 1959)

1) ESTABLISH RAPPORT WITH SYSTEM EMPLOYEES; STUDY ENTIRE JOB TO KNOW EXACTLY WHAT THE PERSON(S) IS DOING.
2) DECIDE ON WHAT THE CATEGORIES OF OBSERVATION SHOULD BE--
    A) HOW COARSE OR FINE THE CATEGORIES OF OBSERVATION OF THE ACTIVITY WILL BE. CATEGORIES SHOULD BE RELATED TO THE PURPOSE OF THE ANALYSIS AND WHAT THE INVESTIGATION HOPES TO FIND.
    B) CATEGORIES SHOULD EXHAUST ALL THE ACTIVITIES THE PERSON(S) ENGAGES IN.
    C) CATEGORIES SHOULD REFLECT OBSERVABLE BEHAVIORS BECAUSE OBSERVABLE ACTIVITIES ARE CLEAR-CUT AND CAN BE INTERPRETED WITH LITTLE OR NO UNCERTAINTY.
    D) TRANSITIONS FROM ONE ACTIVITY TO ANOTHER SHOULD BE INCLUDED.
    E) DEFINE THE LIMITS OF EACH ACTIVITY MAKING SURE THE ACTIVITY IS DEFINED CLEARLY.
    F) LIMIT THE NUMBERS OF CATEGORIES ON THE ANALYSIS BECAUSE TOO MANY CATEGORIES MAKE THE ANALYSIS LENGTHY (IF ANALYSIS IS VERY LONG, SUB-TASK ANALYSES SHOULD BE PERFORMED).
3) SET UP DATA SHEET.
4) DECIDE ON SAMPLING DURATION (THE TOTAL TIME THROUGH WHICH THE OBSERVATION WILL BE MADE).
5) DECIDE ON A SAMPLING INTERVAL IF MORE THAN ONE OBSERVATION IS TO BE MADE (SAMPLING INTERVAL IS THE TIME BETWEEN SUCCESSIVE OBSERVATIONS).

tasks by different persons. Therefore, it can be concluded that TA is a good tool based on its validity, reliability, and versatility.

A more specific evaluation of a particular TA technique is offered by McCormick (1979) in the form of certain evaluation criteria (fig. 9). Regardless of what type of TA the technique is (column, decision table, etc.), it should fulfill these criteria. The technique should be significant and reliable. The method should be comparable to other methods and applicable to different tasks. The method should also be applicable to all stages of system development, as well as easily revised and flexible. The method should provide for unique information recording (which can be fulfilled simply by having an "other" category on the activity sheet).

In addition to McCormick's (1979) evaluation criteria, this author believes a good TA depends on three considerations (fig. 10). A good TA should reflect the competent utilization of the design, the implementation, and the applicability of the method employed. Specifically, the design of the TA must characterize the task at hand for it to be useful. The implementation of the TA must be done properly. That is, the TA must be recorded as objectively as possible to avoid any biasing of the data collection. Biases could confound the validity of the analysis. Applicability is also very important. The TA must be applied in a meaningful and constructive manner for it to be successful. A successful transaction of these three considerations should ensure the success of the TA method. But, if these considerations and their transaction are not observed, the TA will be less than what a good TA should be. For example, a well designed but poorly implemented TA will decrease the merit of the TA. Also, a poorly designed analysis, no matter how well it is applied and carried out, will decrease the analysis' merit. Furthermore, a well-designed and competently conducted TA will also suffer if it is not applied properly. A poorly applied analysis benefits few people.

FIGURE 9

CRITERIA FOR EVALUATING DIFFERENT APPROACHES (McCORMICK, 1973)

1) DOES THE ANALYSIS HAVE SIGNIFICANCE? IS THE INFORMATION PRESENTED IN A MEANINGFUL MANNER REFERRING SPECIFICALLY TO INFORMATION, DECISION, ACTION, AND FEEDBACK ASPECTS?
2) IS THE MEASURE RELIABLE? DOES IT MEASURE WHAT IT'S SUPPOSED TO MEASURE? IS IT IN USE BY DIFFERENT ANALYSTS? CAN IT BE USED ACROSS DIFFERENT JOBS?
3) IS IT A COMPARABLE METHOD? IF SO, IT SHOULD MAKE MEANINGFUL COMPARISONS OF PERFORMING THE SAME TASK POSSIBLE WITH OTHER METHODS.
4) IS THE METHOD APPLICABLE TO DIFFERENT TASKS?
5) IS THE METHOD APPLICABLE TO DIFFERENT STAGES OF SYSTEM DEVELOPMENT?
6) IS THE METHOD EASILY REVISED?
7) IS THE METHOD FLEXIBLE?
8) DOES THE METHOD PROVIDE FOR UNIQUE INFORMATION RECORDING?

FIGURE 10

A GOOD TASK ANALYSIS SHOULD REFLECT THE COMPETENT UTILIZATION OF THE FOLLOWING CONSIDERATIONS:

1) DESIGN
2) IMPLEMENTATION
3) APPLICABILITY

TA is indeed a good tool to use in describing tasks or activities. Actually, it is the only tool that's general enough and specific enough to accommodate a wide variety of tasks. From a psychological standpoint, the evaluation of the TA itself with respect to the study of man-computer interactions is promising. As for Goddard, the evaluation of TA as part of the proposed top-down methodology is yet to be determined. Does the usage of TA help in the understanding of complex computer networks and their interaction with man? That is definitely the important question that hopefully will be answered soon.

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INFORMATION DISPLAY AND INTERACTION IN REAL-TIME ENVIRONMENTS

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Information Display & Interaction in Real-time Environments

Abstract

Modern interactive graphics techniques can provide very high bandwidth data displays. In real-time control environments, effective information interaction rates are a function not only of machine data technologies but of human information processing capabilities and the 4-dimensional resolution of available interaction techniques. This paper examines the available information bandwidth as a function of system's complexity and time constraints in a real-time control environment.

Introduction

Real-time control environments present the system designer with special considerations not necessarily present in traditional data processing environments. In real-time processing, actual physical systems are controlled. These systems are operating in the real world with real costs and benefits associated with successful mission accomplishments and with system failures. Typically the real-time control problems of interest require high information bandwidths to provide the operator with data on mission accomplishment, system, and environmental status data, and to convey control data from the operator to the system. The interaction with a real system in real-time with high bandwidth data processing carries with it requirements for a stringent minimization of operator error and for the minimization of the time taken by the operator to respond with necessary control actions and to confirm the correctness of the actions taken.

Figure 1 illustrates the kind of high level control system which this paper focuses upon. "In the beginning," man effected changes in his environment by the direct use of his own limbs, energy, and sensory systems. In today's real-time control systems, as exemplified by our lunar excavator, man does not partake of the actual task and may even be separated from the ongoing work by long distances and hostile environments.

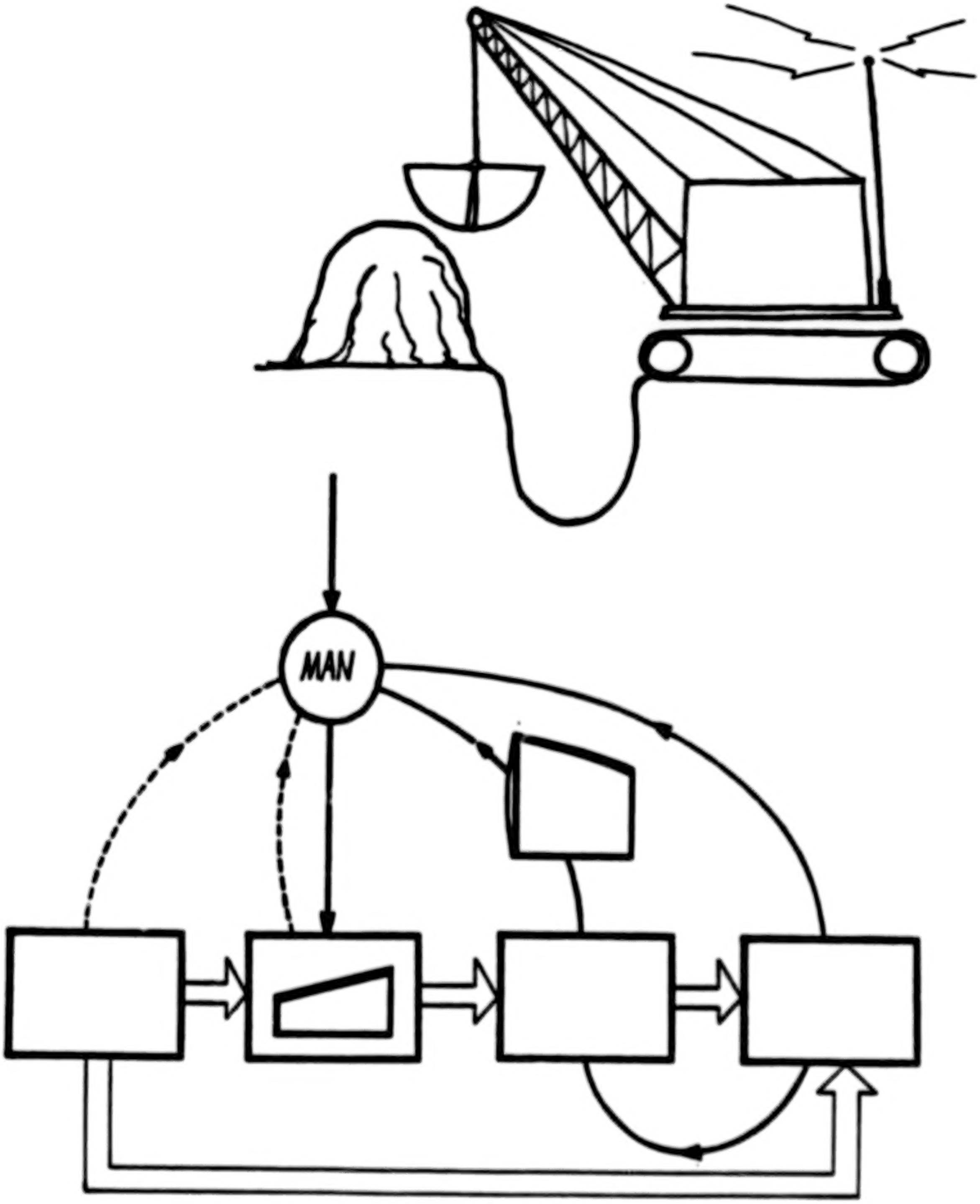

FIGURE 1

(Sheridan & Johannsen, 1976)

Humans interact with the machines performing the work through the intercession of computers. The operator does not interact with the tools or the task itself but with their symbolic abstractions generated and displayed by a computer. These symbolic constructs, rather than the physical objects themselves, are manipulated by the operator. Typically a keyboard or some other interaction technique is the primary instrument for instructing and controlling the physical system, and a text terminal (KCRT) or graphics display terminal is the primary source of information on the status and performance of the controlled system.

This discussion is restricted to information and data rates in a real-time control environment characterized by such a configuration. We assume that all data transmitted to the operator and all control actions are channeled through a computer and its associated peripheral devices for communications. The process-operator world is thus defined by digital encodings and a complete separation of the tools of the task from the controller. This paper asks: under these constraints, what are the effective throughput data rates for supervisor/process interaction?

Contemporary computer and display technologies allow extremely high data rates to be presented to a real-time system operator. In particular, color graphics terminals enable a very broad bandwidth of data transmission from the computer to the human. In turn, a variety of interaction techniques, ranging from touch panels to keyboards, allows the system operator to interact with these displays in real-time. How much information and control can be handled through such an interface? What is the effective control bandwidth?

BANDWIDTH: for our purposes, we will use a primitive notion of bandwidth. This is not intended to be a definitive statement but merely to sharpen our perception of the problem. We define

$B = f(R,C,K) = f(KR/_C)$

where B is bandwidth (bits/second)

R is resolution (area)

C is response constant (time)

K is data density (bits/area)

In this notion, we relate the total amount of data presented through a display device, the resolution of techniques employed to interact with this data, and the time required for an operator response. Bandwidth then gives us the notion of throughput or control bandwidth available or required to exercise operator control of a specific real-time system.

This tentative expression says:

- The longer the required response time, i.e., the more time that can be allowed an operator to perform a control action given an actionable condition, (i.e., one that requires some action on the part of the operator), the lower the needed bandwidth.
- The higher the interaction resolution, i.e., the more precisely an interaction technique can select from among possible alternative control actions, the greater the usable bandwidth.
- The higher the data density, i.e., the amount of data which can be displayed in a unit time interval, the greater the bandwidth.

Data Presentation

Two primary display devices are considered here, the common text terminal (KCRT) and the color graphics display. What are reasonable values of K, data density, for these display devices?

For the KCRT, we assume a traditional display of 24 rows of 80 characters and a set of 96 ASCII displayable characters. The number of characters which may be displayed on the KCRT, using every character display location, is 24*80=1920. A text screen presentation, that is, a full screen of characters, can then be used to represent the state of a variable capable of attaining any one of 96^{1920} different states. This is a reasonably large number. Alternatively, the text screen might be interpreted as representing 1920 different variables, each capable of attaining 96 different states.

The information content of the display, assuming that all states are equiprobable, can then be calculated as:

$$\text{bits} = \log_2 96^{1920} = 1920 \log_2 96$$

which states that the information in a sentence that is 1920 characters long and is constructed from an alphabet of 96 symbols is:

$$\begin{aligned} 1920 \log_2 96 &= 1920(\log_2 10 + \log_2 9.6) \\ &= 1920(3.32193 + 3.2630) \\ &= 1920\ (6.585) \\ &= 12733 \text{ bits} \end{aligned}$$

Since data representing equiprobable states convey the most information, we can then say that the maximum amount of data that can be displayed on this KCRT is 12733 bits at any given instant. For reasons which will be developed later, we will take the minimum display interval to be 1 second. With this definition of our unit time, we know that the maximum data bandwidth of a KCRT is 12733 bits/second.

This is, of course, a much smaller bandwidth then is obtainable with contemporary color imaging or graphics display technology. Here as a representative device we will use a moderate resolution display of 512*512 pixels with a color palette of 24 bits/pixel. This means that there are 512^2 addressable points at which data can be displayed on the face of the display screen. Each data point can be colored on the basis of the 24 bits of pixel color data (3 color dimensions of 8 bits each).[1]

Again, assuming equiprobable states and a 1 second unit time, the bandwidth possible is:

---

[1] The number of colors that may be present on a display simultaneously may be much more constrained than this, given the particular nature of the software implementation, specifically the mapping of colors through a color look-up table.

$$\text{bits/second} = \log_2(2^{24})^{512^2}$$
$$= 512^2 \log_2 2^{24}$$
$$= 512^2 \text{ x } 24 \text{ x } \log_2^{2}$$
$$= 512^2 \text{ x } 24 \text{ x } 1$$
$$= 6{,}291{,}456 \text{ bits/second}$$ [2] or about 6.3 megabits.

Thus, a 512 x 512 display with 24-bits of data per pixel may represent, at a maximum, a single variable with $(2^{24})^{512^2}$ different states. This is quite a large number. Alternatively, it may be interpreted as presenting data on 512^2 different variables, each of which can attain 2^{24} different states.

In terms of raw data display potential, this is certainly a comfortable capability. Few automated control systems require an operator to monitor quite so much data as today's technology can display through a display interface.[3] The question we must turn to now concerns how much of this dense data can be effectively acted upon by the human operator.

The Human Role

Now that we have measures of the amount of data that can be presented at an interface, we turn to consider the capabilities of the human to whom these data are delivered. The rather simple model of the human in a supervisory loop, illustrated in Figure 2, will be used here to structure our discussion of data rates through the human element in the system. On the left side are the major constructs of our view of the human operator. On the right side are the major constructs of our view of the system being controlled.

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[2] Note that this is also identical to the size of the hardware memory, or bit-map, required to drive the display on a bit-mapped device.

[3] The same data density may be achieved on a high density 1024 x 1024 pixel display with only 6 bits of color data per pixel.

SUPERVISORY MODEL

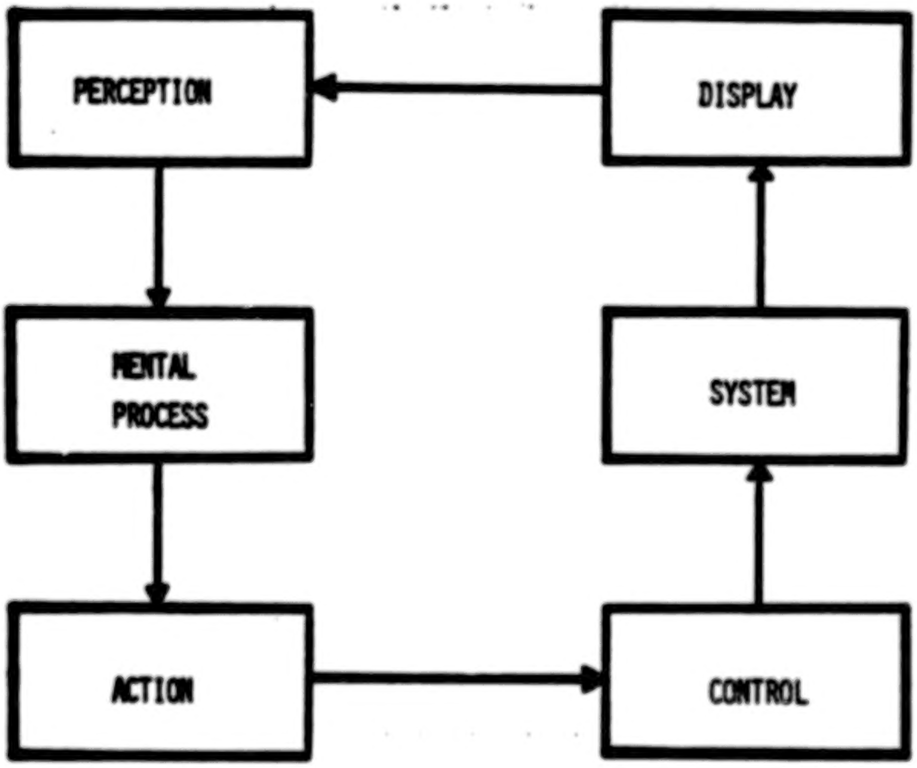

PERCEPTION
DISPLAY
MENTAL PROCESS
SYSTEM
ACTION
CONTROL

FIGURE 2

The CONTROL, SYSTEM, and DISPLAY boxes present a high level view of the controlled system, emphasizing input and output activities. Subsumed under SYSTEM are the computer controlling the physical system and all aspects of the physical system itself. DISPLAY represents physical data display to the human supervisor, the computer-generated output from the control computer. CONTROL represents the physical hardware and digital control data provided to the SYSTEM.

The model of the human suggests three steps in the control process. First, the data presented must be physiologically perceived by the operator. Second, this perceived data must be processed to determine whether an action is required by the operator and, if an action is required, what action should be performed. Third, once an action is determined, the action must be carried out using the controls available. Figure 3 presents an expansion of the MENTAL PROCESS construct. Data captured by the body's sensory apparatus, the sensory inputs, are first filtered by a mask provided from long-term memory. Data making it through the filter pass into short-term memory and thence into long-term memory. The data in short-term memory are used to select an action strategy held in long-term memory.

For our purposes, there are two mental process variables of immediate interest. These are memory span and data acquistion rates. Memory span refers to the amount of data which can be held in short-term memory. Apparently, memory span has physiologically fixed upper limits. Clearly, we are bombarded with very high data rates through our five senses. The filter acts to reduce this barrage to a level with which we can cope. The filter also serves another crucial function: to filter in the important data and to filter out the unimportant data. The determination of what is important and what is not is derived from long-term memory. Thus, incoming data must be packaged as information so that the long-term memory-based filter need not be invoked by the display presentor, or the filter needs to be able to exclude unimportant stimuli on the basis of the stimuli data themselves. If the data presentation bandwidth is too high, if

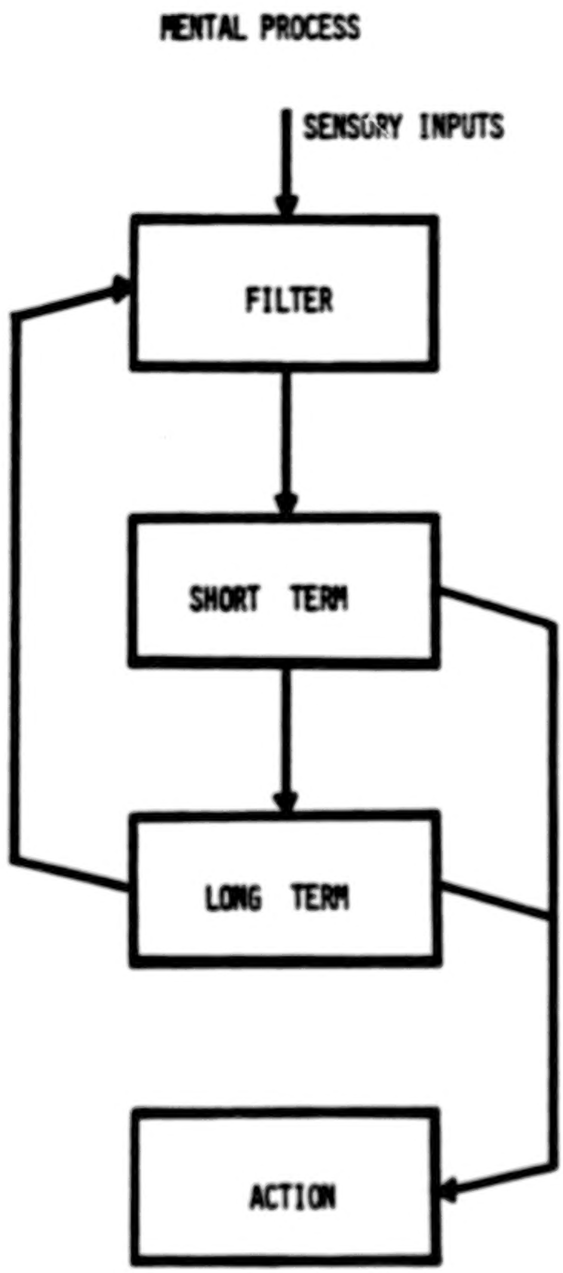

MENTAL PROCESS
SENSORY INPUTS
FILTER
SHORT TERM
LONG TERM
ACTION

FIGURE 3

the time available for mental processing is too short, then data passing successfully through the filter into short-term memory will not be able to pass on into long-term memory. When this occurs, the filter cannot be updated by long-term memory, for long-term memory simply does not have the data it needs to do this. Thus, the supervisor's ability to adapt to changing situations depends upon memory span and the data presentation bandwidth. Similarly, if the data presentation is too rapid for the memory span's capability to absorb data, data will be lost - it will not be consciously perceived.

Data lost are data not acted upon. In real-time control situations this is a circumstance to be avoided.

Ergonomics of Data Perception

We are principally concerned here with two things, the ability to discriminate among stimuli in a set and the ability to detect a stimulus of short duration. The human eye can detect stimuli with very short presentation periods. One tenth of a second provides a generous amount of time to detect a discrete on/off stimulus, such as a light blink. As is well known from cinematography and CRT refreshing techniques, there is a certain amount of visual persistence and a corresponding inability of the eye to perceive breaks in presentation when the presentation rate of discrete images rises above 15 Hz. The eye cannot detect changes in a presented stimuli when presented at a higher rate; this is, of course, what makes motion pictures possible - we do not see the alternation of frame-dark-frame but perceive a continuous image.

The critical duration for our purposes is not the perception of absolute duration by the eye but the accomodation of the eye. Accomodation is the time it takes the eye to change its focal depth, to re-focus. For example, when your eye switches between the view outside the windshield of your car to the reflection of the dashboard on the windshield, your eye is changing its focal depth. Such accomodation is relatively slow. The time taken to accomodate is a function of the difference in focal depths and the age of the eye. By the age of 40, accomodation can take as long as a full second.

Human operators cannot (and will not) stare at a display for hours on end. Attention and focus vary from point to point through the environment of a control room. If we assume that critical displayed information must be fully understood, then we need further to assume that the information must be presented long enough for the operator to focus fully upon it. For this reason, we adopt 1 second as the minimum display duration.

Human ability to discriminate among different one dimensional or univariate stimuli is also limited. There are two types of discrimination which are relevent here: relative and absolute. Relative discrimination compares and rank-orders two stimuli on some dimension. For example, two squares might be compared and rank-ordered on size, with the size of the squares being the one varying characteristic. Absolute discrimination places a single stimulus on some absolute dimensional scale.

For example, consider pure tones in the audible range between 20 and 3000 Herz. Using relative discrimination, most people can discriminate 2800 tones. Forced to use absolute discrimination, most people can only reliably discriminate 5 to 9 separate tones. The problem is not that relative differences in tones suddenly cannot be discerned. The problem is that the different tones cannot be reliably placed in their correct relative location on the dimensional scale of Herz without a reference tone. For one dimensional orderings to become reliable, the number of pure tones must be reduced to about 7 tones for most people, in a way that maximizes the separation between tones.

The discovery that absolute discrimination among univariate stimuli is limited has been immortalized as the "7±2" rule. It holds for shapes, sounds, colors, sizes, loudness, orientation, brightness, hues, length, and most other univariate stimuli. Table 1 from McCormick (1976) shows the number of bits conveyed by different univariate stimuli. The glaring exception in this table is angular line position. The explanation advanced for this is that Western perception of an angular line carries with it coordinating horizontal and vertical axes; we do not see merely the angular line but the angular line superimposed upon the coordinate axes.

This "extra" information is called an anchor and provides another "dimension" to the stimuli. As you might expect, multivariate stimuli can carry more bits of information than one dimensional stimuli. Table 2, also from McCormick (1976), shows the results of experimentation with multivariate stimuli.

Notice that points in space from Table 1 carry only 3.25 bits of information but points in a box carry 4.6 bits. The absolute relations of the points in space are "anchored" by drawing a reference box around them. An estimate of added information

UNI-DIMENSIONAL DISCRIMINATION

McCormick

STIMULUS	ABSOLUTE DISCRIMINATION	BITS
PURE TONES	5	2.3
LOUDNESS	4-5	2. - 2.3
SIZE OF OBJECT	5-7	2.3- 2.8
BRIGHTNESS	3-5	1.7- 2.3
HUES	12-13	
ANGULAR LINE POSITION	26	4.5
DOT POSITION (IN SPACE)	10	3.25
LENGTH	7-8	2.8

TABLE 1

CHANNEL CAPACITY / MULTIDIMENSIONAL STIMULI

STIMULUS	ABSOLUTE DISCRIMINATION	BITS
SIZE + BRIGHTNESS + HUE	18	4.1
FREQUENCY + INTENSITY + RATE OF INTERRUPTION + ON-TIME FRACTION + TOTAL DURATION + SPATIAL LOCATION	150	7.2
LOUDNESS + PITCH	9	3.1
POINTS IN SQUARE	24	4.6

TABLE 2

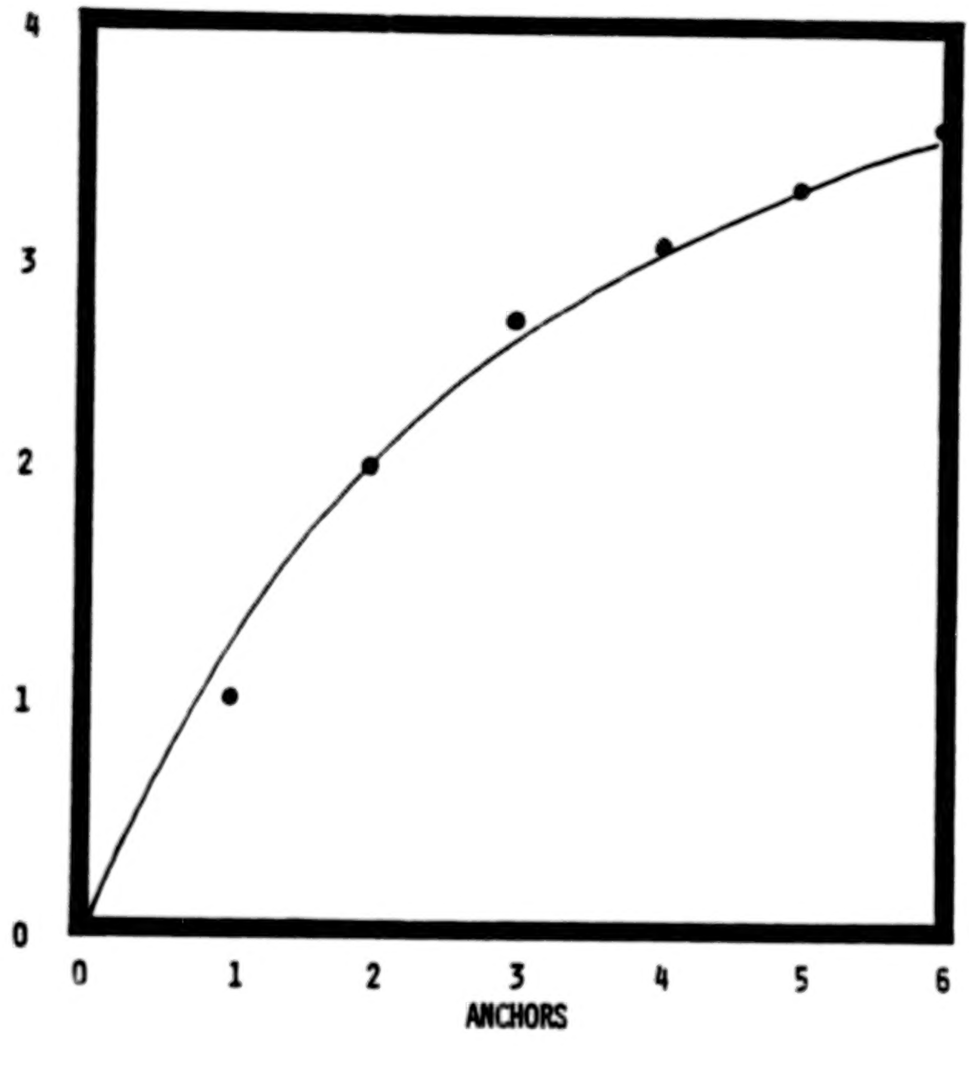
provided by anchors is given in Figure 4. The information contributed appears to be an inverse exponential function of the number of anchors, rising asymptotically to about 4 bits. The implication is that, given current knowledge, we can add about 4 bits of information to the basic 7±2 absolute univariate discrimination by using anchors and multivariate stimuli.

Steinbuch (1962) has estimated the maximum flows of information as shown in Table 3. Note the maximum upper limit of 16 bits on consciousness. This includes all conscious mental processing, not just the processing of input stimuli. The processing of sensory stimuli apparently requires about half the conscious information processing capability of the brain. Note too the extremely slow rate at which information flows into long term memory. In emergency situations for which adaptation is required, this rate represents a maximum upper limit on the speed at which the operator can process this adaptation into long term memory - i.e., update the perceptual filters.

The "7±2" limitation is apparently related to the memory span of short term memory and is a physiological constraint on mental information processing. It translates for our purposes to a bandwidth of about 3 bits/second. Thus, even though megabits of information can be presented over a contemporary display device, the human operator can only process about 3 bits/second from these megabits in our postulated automated control environment.

Control Tasks

So far we have seen control bandwidth constricted to about 3 bits/second. We have looked at perception and subsequent mental processing for interpretation to complete the loop. We need still to consider the ergonomics of the control action itself. In this discussion, the control actions which may be taken are those which interact with the control computer through the display itself. The control actions are interactive and can be classified as consisting of the following interaction tasks (Foley, 1981): selection, positioning, orienting, pathing, quantifying, and text manipulation. Other subsidiary



INFORMATION CONTRIBUTED BY ANCHORS (IN BITS)

FIGURE 4

MAXIMUM FLOW OF INFORMATION

BITS/SECOND

(STEINBUCH: 1962)

SENSORY RECEPTION	1 000 000 000
NERVE CONNECTIONS	3 000 000
CONSCIOUSNESS	16
PERMANENT STORAGE	0.7

TABLE 3

tasks which interactively affect an image on the display are controlling interaction tasks: sketching, stretching, manipulating, and/or shaping graphical images. These interaction tasks are enabled through specific configurations of hardware and software. An interaction technique is a specific configuration of hardware and software which allows the user to perform an interaction task. Here we consider interaction techniques for control exercised through an automated interface. Of interest is how rapidly the user can respond with a control directive and how accurately the response can be made. From this, we derive our concepts of resolution and data on possible control bandwidths.

Figure 5 lists the major interaction techniques available. The first two, touch panel and light pen, enable a direct interaction with the screen display. The other groups represent indirect interaction techniques. Although included for completeness, chord and voice interaction techniques will not be considered here, chord because it has been shown to be generally inferior to other available interaction techniques and voice because we are concerned with control interactively exercised through the display itself.

Power Region Interaction Technique

The only unfamiliar interaction technique is the Power Region technique, developed during the course of current work for NASA. The Power Region interaction technique maps keystrokes from a control key set, as shown in Figure 6 into a subregion of a previously selected region on the display. The initial region selected is, by default, the full screen. Since each keystroke increases resolution by a factor of 9, the achievable resolution is given by

$$R = \frac{XY}{9^{\text{KEYSTROKES}}}$$

where X and Y are the heighth and width of the display in pixels, and KEYSTROKES is the number of keystrokes made during selection. The technique takes its name from this power relation.

As each subregion is selected, it is displayed in reverse video on a black and white

INTERACTION TECHNIQUES

TOUCH PANEL
LIGHT PEN

TABLET & STYLUS
MOUSE
JOYSTICKS (ABSOLUTE, VELOCITY)
TRACKBALL
CURSOR CONTROL KEYS (TEXT, CROSSHAIRS)
POWER REGION CONTROL KEYS

ALPHANUMERIC KEYBOARD
FUNCTION KEYBOARD
SOFT KEYS

CHORD
VOICE

FIGURE 5

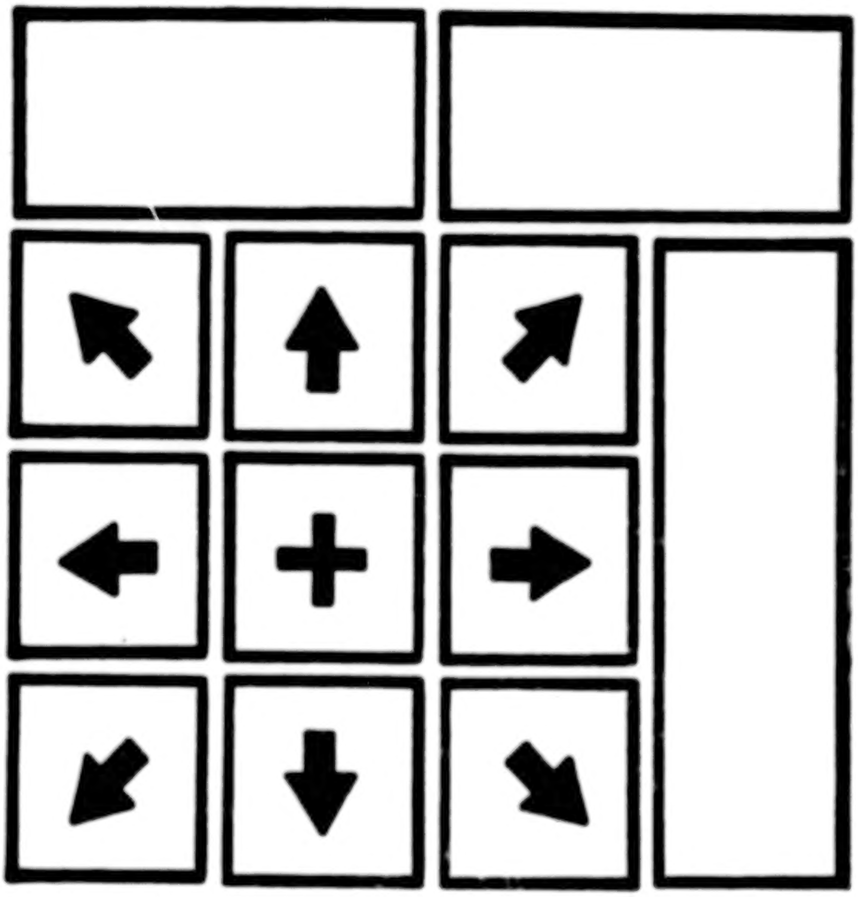


FIGURE 6

device or by some indicative background color on a color display. As the next subregion is selected, the previous subregion reverts to normal display. Figure 7 illustrates the increase in resolution obtained by successive keystrokes. The small black square represents the subregion selected at the conclusion of 4 keystrokes. Note that there is no change in hand modality as the hands remain poised on the keyboard. The following shows the achievable resolution by keystroke on a 512 x 512 display:

$$262144 \div 9^0 = 262144 = 512^2$$

$$262144 \div 9^1 = 29126 = 171^2$$

$$262144 \div 9^2 = 3236 = 57^2$$

$$262144 \div 9^3 = 359 = 19^2$$

$$262144 \div 9^4 = 40 = 6.5^2$$

$$262144 \div 9^5 = 4 = 2^2$$

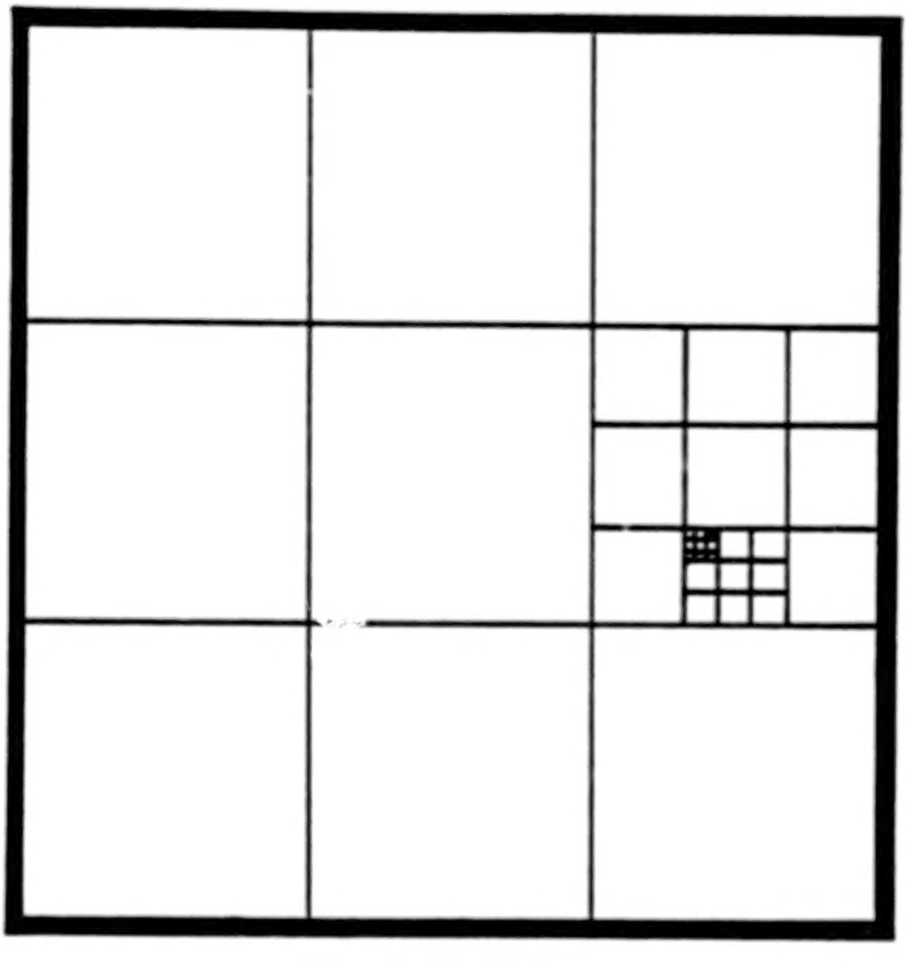
Interaction Technique Analysis

The tables which follow have been adapted from Foley (1981) and are evaluations of various characteristics of these different interaction techniques (Figure 8). Of particular interest are the data for resolution and response times observed in various experimental settings. Unfortunately, response times for some interaction techniques have not been published in the literature reviewed and are yet subject to experimental determination.

Published response times range from 1.3 to 11.7 seconds to for accurate completion of a control action using the interaction techniques studied. There is little intuitive reason to suppose that the unmeasured response times would fall significantly outside this range. For a full explanation of these tables, the reader is referred again to Foley, except for the analysis of the Power Region interaction technique.

The Power Region technique is primarily a selection or positioning technique. The cognitive load is high because the technique requires that the user geometrically map the keypad arrangement into successively smaller subregions. However, the perceptual load is light because selected regions are displayed by contrast techniques and the motor load

BEST DOCUMENT AVAILABLE



POWER REGION RESOLUTION

FIGURE 7

BEST DOCUMENT AVAILABLE

INTERACTION TECHNIQUES (adapted from Foley,1981)

LIGHT PEN

TASKS	SELECT	POSITION	ORIENT	PATH	QUANTIFY	TEXT
Cognitive Load	L	L			L	
Perceptual Load	L	L			L	
Motor Load	M	M			M	
Visual Acquisition	L	L			L	
Motor Acquisition	M	M			M	
Learning	L	L			L	
Fatigue	M	M			M	
Error	L	M			M	

RESOLUTION 2^2 PIXELS

RESPONSE TIME 1.8 to 6.5 seconds, depending upon task

CURSOR CONTROL KEYS

TASKS	SELECT	POSITION	ORIENT	PATH	QUANTIFY	TEXT
Cognitive Load	H	H				
Perceptual Load	H	H				
Motor Load	M	M				
Visual Acquisition	H	H				
Motor Acquisition	M	M				
Learning	L	M				
Fatigue	L	L				
Error	M	M				

RESOLUTION 1 character cell TEXT cursor; 1 PIXEL CROSSHAIRs

RESPONSE TIME 2.2 - 11.7 seconds

FIGURE 8

INTERACTION TECHNIQUES

TABLET & STYLUS

TASKS	SELECT	POSITION	ORIENT	PATH	QUANTIFY	TEXT	SELECT
	MOVEMENT						CURSOR MATCH
COGNITIVE LOAD	H	M			M		M
PERCEPTUAL LOAD	M	M			M		M
MOTOR LOAD	M	M			M		M
VISUAL ACQUISITION	H	M			M		M
MOTOR ACQUISITION	M	M			M		M
LEARNING	H	M			L		L
FATIGUE	H	L			M		M
ERROR	M	L			L		L

RESOLUTION TO 1 PIXEL

RESPONSE TIME 2.0 - 2.5 SECONDS

TOUCH PANEL

TASKS	SELECT	POSITION	ORIENT	PATH	QUANTIFY	TEXT
COGNITIVE LOAD	L	L				
PERCEPTUAL LOAD	L	L				
MOTOR LOAD	L	L				
VISUAL ACQUISITION	L	L				
MOTOR ACQUISITION	L	L				
LEARNING	L	L				
FATIGUE	L	L				
ERROR	DEPENDS UPON RESOLUTION					

RESOLUTION 2 CM SQUARE

RESPONSE TIME

FIGURE 8 CONTD.

INTERACTION TECHNIQUES

TRACKBALL

TASKS	SELECT	POSITION	ORIENT	PATH	QUANTIFY	TEXT
Cognitive Load	M	M			M	
Perceptual Load	M	M			M	
Motor Load	M	M			M	
Visual Acquisition	L	L			L	
Motor Acquisition	M	M			M	
Learning	M	M			M	
Fatigue	L	L			L	
Error	M	M			M	

RESOLUTION	to 1 PIXEL
RESPONSE TIME	2.5 - 3.0 seconds

MOUSE

TASKS	SELECT	POSITION	ORIENT	PATH	QUANTIFY	TEXT
Cognitive Load	M	M			M	
Perceptual Load	M	M			M	
Motor Load	M	M			M	
Visual Acquisition	M	M			M	
Motor Acquisition	M	M			M	
Learning	L	M			L	
Fatigue	M	L			M	
Error	M	M			M	

RESOLUTION	to 1 PIXEL
RESPONSE TIME	1.3 to 2.0 seconds

FIGURE 8 CONTD.

INTERACTION TECHNIQUES

ALPHANUMERIC KEYBOARD

TASKS	SELECT	POSITION	ORIENT	PATH	QUANTIFY	TEXT
COGNITIVE LOAD						H
PERCEPTUAL LOAD						H
MOTOR LOAD						M
VISUAL ACQUISITION						M
MOTOR ACQUISITION						M
LEARNING						M
FATIGUE						M
ERROR						M

RESOLUTION	TO 1 PIXEL
RESPONSE TIME	1.5 CHARACTERS/SECOND TO 5 CHARACTERS/SECOND

INTERACTION TECHNIQUES

POWER REGION

TASKS	SELECT	POSITION	ORIENT	PATH	QUANTIFY	TEXT
COGNITIVE LOAD	H					
PERCEPTUAL LOAD	L					
MOTOR LOAD	L					
VISUAL ACQUISITION	L					
MOTOR ACQUISITION	L					
LEARNING	H					
FATIGUE	(M)					
ERROR	L					

RESOLUTION	XY/9$^{\text{KEYSTROKES}}$
RESPONSE TIME	(1 SECOND) { if resolution required

FIGURE 8 CONTD.

INTERACTION TECHNIQUES

FUNCTION KEYBOARD

TASKS	SELECT		POSITION	ORIENT	PATH	QUANTIFY	TEXT
	SCAN	LABEL					
Cognitive Load	H	L					
Perceptual Load	H	L					
Motor Load	M	L					
Visual Acquisition	H	M					
Motor Acquisition	M	M					
Learning	M	L					
Fatigue	H	L					
Error	H	L					

RESOLUTION PROGRAMMABLE

RESPONSE TIME

SOFT KEYS

TASKS	SELECT	POSITION	ORIENT	PATH	QUANTIFY	TEXT
Cognitive Load	L					
Perceptual Load	L					
Motor Load	L					
Visual Acquisition	M					
Motor Acquisition	M					
Learning	L					
Fatigue	L					
Error	L					

RESOLUTION 1/2 square inch

RESPONSE TIME

FIGURE 8 CONTD.

is low because it requires only keystrokes in a well-defined region of the keyboard (see the soft key analysis). Visual and motor acquisition are low for the same reasons. Because the mental technique of mapping and moving from one subregion to another must be coordinated with physiological control of the fingers on the set keypad, learning is seen as high. Fatigue would be comparable to fatigue encountered with soft keys and function keyboards. However, the brightness of the contrast of reverse video over large regions on black/white displays and the possible flash when changing such subregion display states may prove visually fatiguing to operators of such devices. The smallness of the selected subregion at higher resolutions may also induce visual fatigue. Error is seen to be low due to the quality of the feedback and the discrete actions of the technique.

The resolution of the technique is $XY/9^{\text{KEYSTROKES}}$. Clearly, the response time is a function of the degree of resolution required. Because the hand modality does not change and the fingers remain positioned on the keypad, the response time of 1 second is estimated from comparable keystroke data for data entry on numeric keypads. Further experimentation will evaluate the Power Region technique more adequately.

Resolution, Error, and Response Time

There is a clear interaction among error, resolution, and response time with any interaction technique. The higher the required resolution, the longer the response time needed to remove positioning error. The relations among resolution, response time, and error follow Fitt's Law:

$$T = Q + K \log_2 \frac{A}{B/_2}$$

where

T = time of positioning move

A = length of positioning move

B = size of target

Q & K = empirically determined constants.

Fitt's Law simply says that the farther away and the smaller a target is, the longer it takes to position to the target.

From Fitt's Law and the above assessment of control interaction techniques, we estimate that on the average a control action will require at least 2 seconds. If the throughput from mental processing is 3 bits/second and it takes 2 seconds to make the control action decided upon, our bandwidth is then reduced to 3 bits/second ÷ 2 = 1.5 bits/second. This then, is our bottom line - the effective control bandwidth that we can expect is only about 1.5 to 2 bits/second through an automated interface.

System Complexity

We now turn to examine the interrelation betweeen effective control bandwidth and system complexity. By system complexity, we refer simply to the number of controllable variables, their control interdependencies or relationships, and to the time constants of these variables.

Simple Systems

First, let's look at a very simple system. From a supervisory point of view, a personal pocket transistor radio is an extremely simple system. It has a variable power source (battery), on/off/gain control, and a tuning control, with a relation between the duration of the on-state and power source longevity. If we consider this radio operating in steady state, we find that the time constant for the power source is simply the life of the battery; the time constant for gain is a function of the remaining battery strength; and the time constant for tuning is a function of circuit drift.

The required operator response times extend toward infinity (in units of seconds) without endangering the health of the system or its mission functions. Hence, for this simple system's interactive control, with such extremely long time constants, we require only a very small control bandwidth. Almost any interaction technique will serve.

Figures 9 and 10 illustrate the adaption of a text interaction technique to control such a system. (Admittedly, the use of graphics here might be considered overkill!)

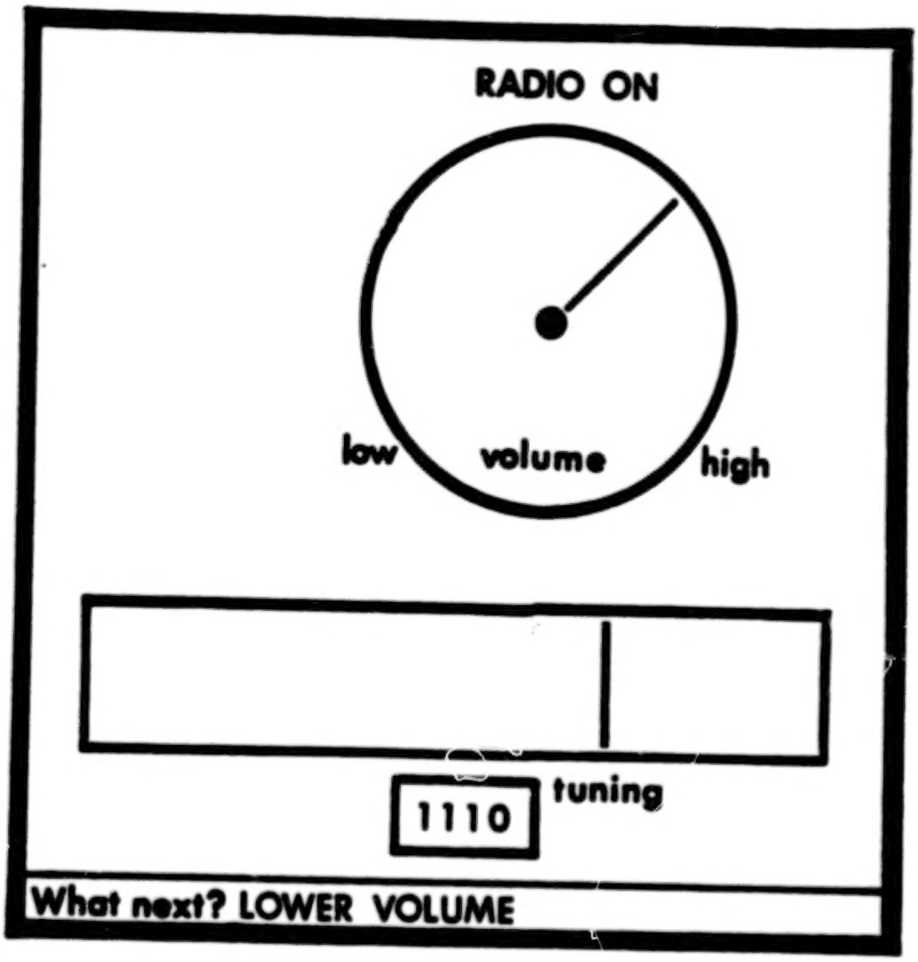
Complex System

Now we will consider a somewhat more involved system, somewhat akin to a contemporary nuclear power plant. We will assume that the number of displayed variables is 2500. This is clearly within the data display capabilities of a 512 by 512 by 24 bit display. The square root of 2500 is 50 and 512/50 is about 10. This says that approximately 10^2 pixels per variable display are available, or approximately one standard character's area within the screen size. Since $2^{24} = 16,777,216$, we have available, for practical purposes, the feasible representation of any variable as continuous.

Because interaction techniques provide us with the capability to resolve to 1 pixel, we may then have as many as 10^2 control actions which can be independently designated for each displayed variable. Assuming equiprobable states, the displayed data provide $2500 \log_2 2^{24} = 60000$ bits. If our control action data rate is as high as 2 bits/second, then it will require 30000 seconds or about 8 hours and 20 minutes to interact with some degree of intelligence with every displayed variable.

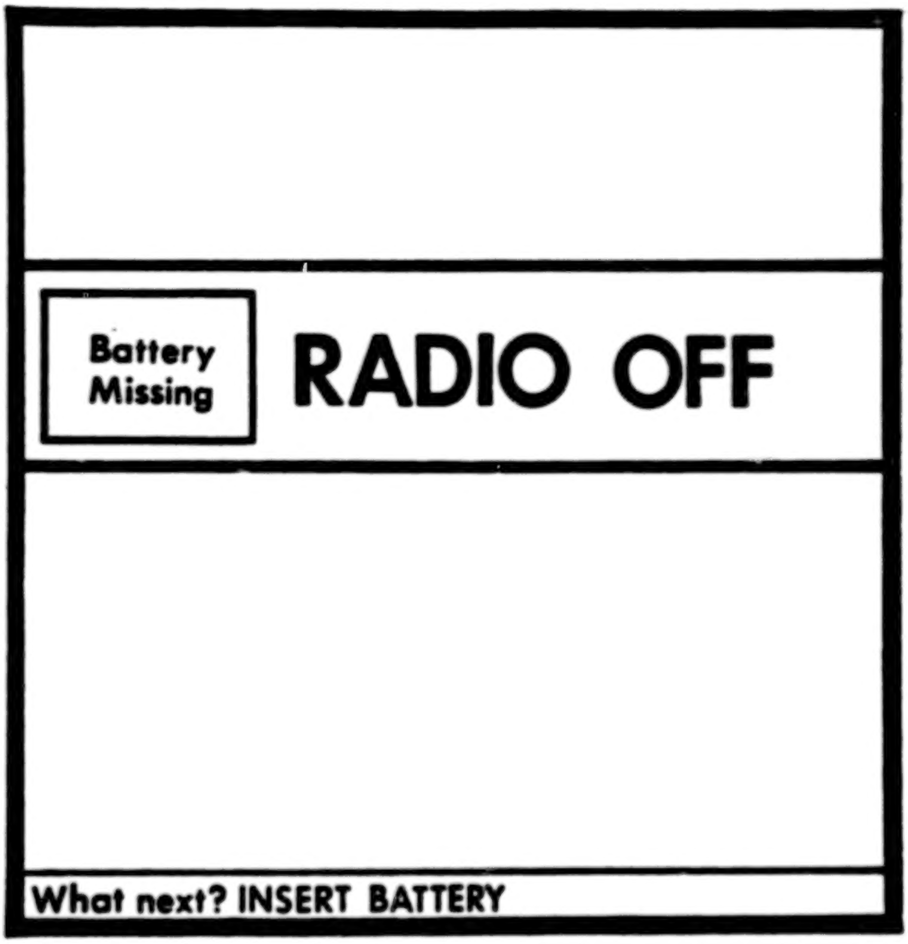
For our interaction technique, we will postulate a lightpen. Imagine pointing the light pen at every display element in a controlled random order, i.e., every element will be interacted with before repetition begins. This means 2500 separate randomly determined pointing actions, each one requiring about 2 seconds. This gives us $2500 * 2 = 5000$ seconds or about an hour and 20 minutes just to go through the motion sequences. This estimation is without regard for the information content of the display or for the correct selection of a control action and with a low resolution for the light pen.

To cope with the additional 24 bits of data represented by each element at an effective rate of 2 bits/second would require some 12 seconds per display element. For the entire screen, this requirement is $12 \times 2500 = 30000$ seconds. This is somewhat high


RADIO ON
low
volume
high
1110
tuning

What next? LOWER VOLUME

FIGURE 9



Battery Missing

RADIO OFF

What next? INSERT BATTERY

FIGURE 10

because it does not reflect the truncation of mental processing at the level of absolute discriminability, i.e., at about 2.3 bits. If we subtract this, we obtain 24-2.3=21.7 effective bits and 10.5 seconds per element, or about 26000 seconds.

Now note that this assumes equally likely states and assumes instantaneous identification of a display/control element's coordinate position and from that the identity of the display/control.

A distribution of state probabilities will radically decrease mental processing time because, we assume, most variables will maintain a normal condition most of the time. Assuming a 9:1 ratio of acceptable to actionable states, the minimum information content of the screen is

$H = 2500 \times .469 = 1175$ bits and

1175 bits/2 bits/second = 590 seconds

= 10 minutes

for a complete screen control scan, explicitly interacting with each actionable variable. (This assumes a constrained sequential processing order.) Thus, the minimum time constant in this system using such an approach, cannot be greater than 10 minutes!

Static monitoring activity

In static monitoring activities, (within a presumably well designed system) acceptable, nonactionable states should have at least a plurality probability. This means an information content of

$H = \log_2 1/P$ where $P \quad .5$

If the well-designed system runs normally with non-actionable states having a probabilty of .9, then

$H_{ok} = \log_2 1/.9 = \log_2 .1111$

$H_{bad} = \log_2 1/.1 = \log_2 10;$

and

$H = \quad P(i) \log_2 P(i)$

$$= .9 \log_2 .1111 + .1 \log_2 10$$

$$= .1368 + .3322 = .469$$

Hence, compare

$$H = M \log_2 N$$

for equiprobable and the 9:1 probabilities:

$$10 = 10 \log_2 2 = X \log_2 469 \text{ ; and so } \quad X = 20.$$

Thus, twice as many display/control elements can be handled by the operator with a 9:1 state distribution than can be managed with an equiprobable state distribution of actionable and non-actionable states.

Multivariate Displays

The foregoing discussion has focused upon univariate displays. Much of the pessimism revealed is due to the use of such one dimensional displays. There is much interest, as a result, in multivariate or integrated displays. Integrated displays construct a single image from multivariate data, including data from entirely different coordinate scales. Such displays are often called icons. Icons are being explored as visual presentation methods for chunking data. Star and Face icons are illustrated in Figure 11. The Star is essentially a polar plot of several variables. The middle of the plot and the perimeter of the plot represent actionable states. A datum on a specific variable is plotted along a given angle and is joined by a straight line to the adjacent data. With a glance the viewer can grasp that all variables are "OK" or if there is an actionable state among them.

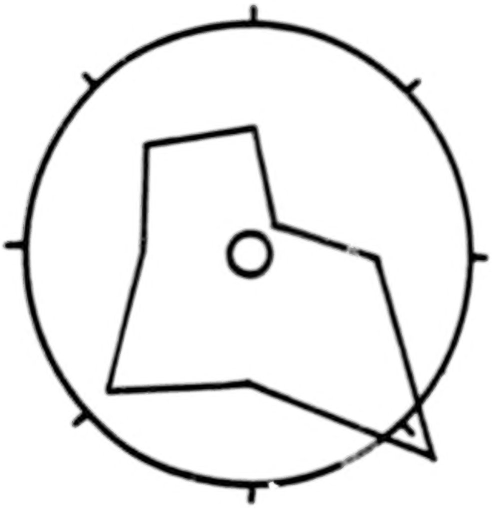
The Face icon associates system variables with attributes of the features of the face. For example, the state of one variable might determine the length of the eyebrows while the state of another might determine their angle. From 12 to 20 variables have been successfully integrated in face icons for different purposes.

A Reference icon, proposed here, is an icon presentation on two superimposed visual planes. The "reference" icon resides on the "back" plane and symbolizes the

ICONS

VISUAL PRESENTATION METHODS FOR CHUNKING DATA

STAR



FACE

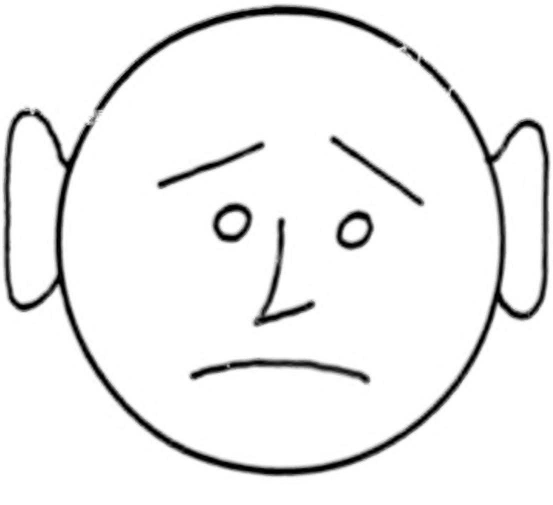


FIGURE 11

expected system states. The "system" icon resides on the "front" plane and symbolizes actual current system states. The system icon may appear much like a transparency overlay. Separation between the two images on a color display might generate increasing dissonant color schemes.

The Reference icon notion provides a high information content because it anchors the system icon. This enables difference judgments as well as absolute judgments and hence greater subtlety in comprehending the operating system's current state.

A Reference icon might be implemented in any one of numerous ways. Consider the application of the Face icon through a Reference icon approach. The face is composed of several discrete parts which are perceived as a whole or gestalt image, i.e., as "Joe" or "Susan". High speed video disk allows the storage of different facial component images which can be assembled on the fly. This capability allows the supervisor to customize the reference image to establish some congruency or "fidelity" between the display and the supervisor's mental model of the system. It also allows the automated control system to assemble the system or overlay image on the basis of current system state.

The use of multivariate or integrated displays is, as yet, relatively unexplored. However, the need for higher control rates is driving research in this area.

Conclusions

Effective interactive control data rates are severely restricted through an automated (screen) interface. Univariate processing is particularly slow. Human capabilities limit us to an upper limit of 10 bits/second of throughput data processing. Human use of control instruments, such as the interaction techniques presented, drives this rate down by a factor of 3. Effective control data transmission rates are on the order of only 2 bits/second. Figure 12 illustrates the conclusions of this discussion.

THE BANDWIDTH FUNNEL

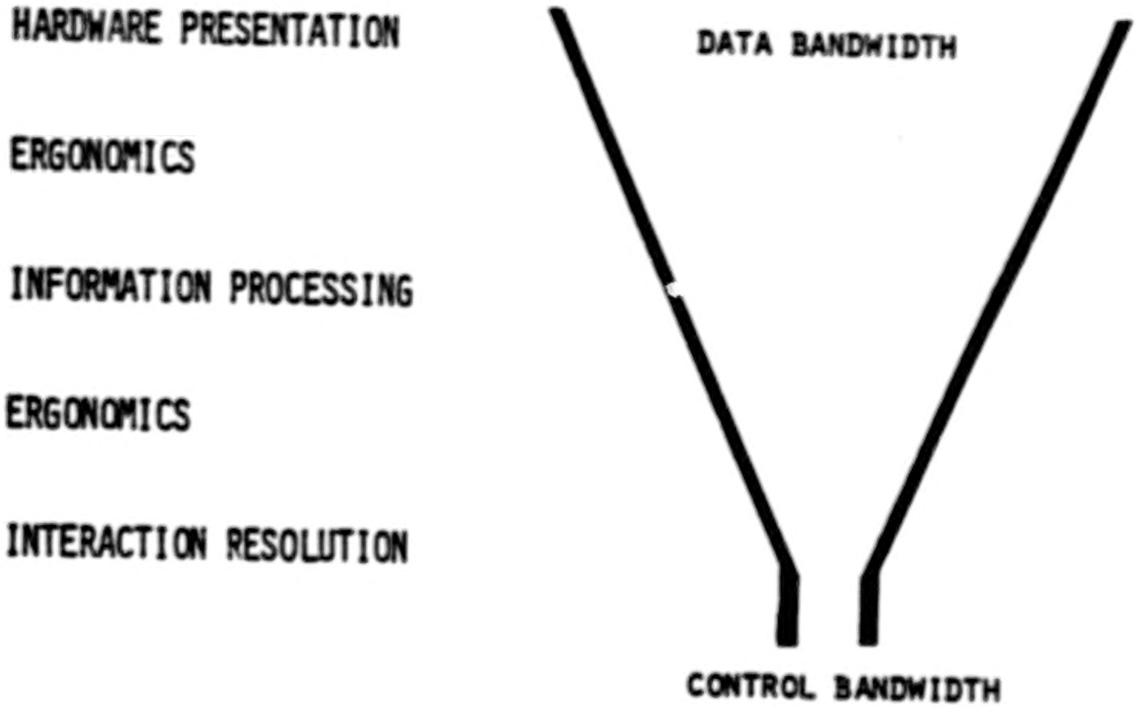

HARDWARE PRESENTATION
ERGONOMICS
INFORMATION PROCESSING
ERGONOMICS
INTERACTION RESOLUTION
DATA BANDWIDTH
CONTROL BANDWIDTH

FIGURE 12

Operational Implications

The fastest we can go in a real-time environment when controlling through an automated interface of the type discussed here approximates throwing two on/off switches or making a gross adjustment on a dial in a second.

The integration of system data and control choices on the interface requires iconic methods to chunk both incoming data and outgoing control. Chunking incoming data is under investigation, but virtually nothing is known about chunking outgoing control.

Interactive control displays need to be designed so that control data rates in crisis/critical/failure situations do not overwhelm the information processing capabilities of the controller. In these cases, the effective data control rate may be reduced to less than a bit per second. System design needs to start, then, with a definition of the required control data rates in extreme situations rather than with a definition of the normal operating characteristics.

The minimum cycle time from one variable to the next will include recognition of confirming feedback, which this discussion has not included. With feedback, this minimum cycle time may be greater than 3 seconds.

Catastrophic events are (or should be) extremely low probability events. Supervisor response time will then tend to be perceptibly longer as the supervisor puts together a perception of the event and an appropriate control or guidance strategy. This implies that screen or display format must change less rapidly under critical situations than may be allowed during normal operations.

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SUMMARY, COMMENTS, AND EVALUATION

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SUMMARY, COMMENTS, AND EVALUATIONS

The human factors conference offered a wide variety of themes and concepts to give an overview of the human factors field. The intent of this symposium was to introduce interested Goddard personnel to the history, objectives, and applications of human factors principles. Appropriately, the invited speakers were distinguished professionals currently involved in research and the implementation of human factors guidelines in applied settings. One hundred and thirty people were present for the plenary presentations on the first day. Approximately 35-40 people attended each workshop session.

Comments on the Plenary Sessions

Overall ratings on the evaluation form provided with the registration folder ranged from good to excellent for the first day of activities. Twenty-seven percent of the forms were returned; this figure was slightly above the expected return rate. The attendees' response to these plenary presentations was very favorable. Dr. Chapanis' clear, comprehensive presentation of the history of human factors aspects of system design was thought to be especially informative to those unfamiliar with the concept of "human factors". Mr. Jenkin's speech covered the analysis of new and existing control rooms with regard to human factors issues. A majority of attendees rated Dr. Shneiderman's talk as practical, applications oriented, and most pertinent to their own considerations. He also gave data supporting his recommendations. Dr. Foley presented a talk on interactive techniques that was reinforced by showing a film he produced on computer graphics. Reactions to the Human Factors Research Group (HFRG) were generally optimistic. There was a caution to define the user population and to concentrate on direct applications of human factors techniques rather than concentrating solely on research. Another comment asserted that the costs/benefits of human factors considerations are the main issues, with user satisfaction and efficiency being of secondary importance.

Other human factors activities the participants saw as pertinent to GSFC include:

- Formulation of guidelines.
- User involvement in system specifications.
- Awareness of problems with software development.
- Reduction of data for display—how to handle large amounts of data.
- Review computer hardware interactive graphics capabilities to support operations—too limited at present.
- Provide overview of human factors concerns to Institutional management of GSFC.

Comments on the Workshop Sessions

The workshops presented on the second day were planned to cover specific human factors research topics relating to operations at GSFC and to allow personnel to interact with the human factors experts. There were four parallel sessions comprised of eight workshops. Topics were varied, and response to the question, "Which of the sessions was most beneficial and which was least beneficial?" varied with each participant, indicating that an acceptable mix of topics were covered. There was a 15% return rate for the second day's evaluation sheet. Overall, the workshops were rated as good. Participants agreed that the structure of day two was good, allowing for flexibility of choice between sessions.

Perhaps the term "workshop" was an inappropriate title for the sessions of day two. In general, there was less interaction between presenters and participants than anticipated. Rather than seeking theoretical approaches, the participants were looking for applied techniques to handle human factors problems. Many participants were aware of areas within their work environment that needed improvement, and they seemed anxious to have the HFRG offer solutions. As one Goddard employee stated, "It's difficult to tell management that a new system being installed is not as good as another. When they ask why, you can only refer to your experience, and that doesn't carry much weight. Implementers sometimes present a new system with no concern for the human factors involved in carrying out the new system. What is needed is concrete data to present to management to demonstrate why some systems are better than others." On the other hand, it was noted that display specifications are often arbitrary and very dynamic. Another comment supporting the idea of quantification surfaced when a participant asked one of the conference organizers when there would be a NASA/Goddard document that would allow personnel to see the impact of human factor considerations.

There were several comments regarding the mechanics of [illegible]. Suggestions to improve a future symposium included:

- o Increase audio-visual support.
- o Consider more multi-media presentations; film used was good.
- o Limit talks to one hour or provide adequate breaks.
- o Present two tracks of presentation—one for interested novices with emphasis on overview and one for involved designers with an emphasis on tradeoffs of approaches.
- o Ideally, have proceedings to hand out at the beginning of the conference.

HFRG Critique of Symposium

At a follow-up meeting of the HFRG on Thursday, May 27, 1982, members agreed that they had accomplished their goals of informing GSFC personnel of their research and applications plans; introducing ideas to create awareness of human factors considerations; and welcoming interaction with the HFRG. As an extension of this introduction, the group suggested the possibility of a briefing for top management based on the format of the first day but on a smaller scale. Further, it would be desirable to establish better coordination with headquarters, other centers, and agencies in order to establish a stronger human factors network.

At the time of the Symposium, the HFRG group had been in existence only a period of four months. Several participants noted the lack of documented material for reference. Therefore, the HFRG decided to accumulate and document information as a major, ongoing activity for the group. Specifically, it was decided to produce a report on the work with the ERBS project, documenting the problems presented for the group to consider, the group's recommendations, and how ERBS responded. Also, by the end of August, 1982, there will be an annotated human factors bibliography available for reference.

It was further decided to review another system design currently in progress. The Mission Planning Terminal (MPT) design review was to be finalized in the near future. An attempt would be made to offer guidelines to be incorporated in their software specifications. A diary would be kept on all phases of human factors work with the MPT group.

The HFRG will continue evolving guidelines and mechanisms for incorporating human factors into the system engineering process, especially during specification and design. With human factors a growing part of system design considerations at GSFC, there will be a concerted effort to document all applications of human factors recommendations. Access to both successes and failures will provide a stronger basis for applying future human factors guidelines.

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PREPARED BY
GEORGE MASON UNIVERSITY
WITH THE SPONSORSHIP OF
NASA-GODDARD CONTRACT NAS5-26852
JUNE, 1982

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BIBLIOGRAPHIC DATA SHEET

1. Report No. NASA CP-2246

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle HUMAN FACTORS CONSIDERATIONS IN SYSTEM DESIGN

5. Report Date January 1983

6. Performing Organization Code

7. Author(s) Christine M. Mitchell, Paula M. Van Balen, and Karen L. Moe, Editors

8. Performing Organization Report No.

9. Performing Organization Name and Address

George Mason University
4400 University Drive
Fairfax, Virginia 22030

10. Work Unit No.

11. Contract or Grant No. NAS 5-26952

12. Sponsoring Agency Name and Address

Goddard Space Flight Center
Greenbelt, Maryland 20771

13. Type of Report and Period Covered Conference Publication

14. Sponsoring Agency Code

15. Supplementary Notes

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Karen L. Moe: Goddard Space Flight Center, Greenbelt, Maryland.

16. Abstract

This volume contains the proceedings of the NASA-Goddard Symposium on Human Factors Considerations in System Design, held May 25-26, 1982 at Goddard Space Flight Center in Greenbelt, Maryland (day 1) and the University of Maryland in College Park, Maryland (day 2). The purpose of this symposium was to introduce and explore the range of topics included in the general area of human factors as applied to system design. Special attention was given to issues focusing on human-computer interaction. The plenary session included talks discussing: the general background and applicability of human factors as a tool in system design, the use of human factors in nuclear power plant control rooms, the human factors dimensions of software design, and a critique, from a human factors perspective, of interaction devices and techniques used in the human-computer interface. The workshop topics included: guidelines on ergonomic aspects of control room design, a case study of a human-engineered satellite control room, conceptual models of information processing, methodologies for human factors research, mechanics of conducting a task analysis, and information display and interaction issues in real time environments. This document contains papers from each speaker and workshop session, summaries of the discussion and evaluation, and viewgraph presentation material.

17. Key Words (Selected by Author(s))

Human Factors
Ergonomics
Control Room Design
Human - Computer Interface
Human - Computer Interaction

18. Distribution Statement

Unlimited - Unclassified

Subject Category 54

19. Security Classif. (of this report) Unclassified

20. Security Classif. (of this page) Unclassified

21. No. of Pages 400

22. Price* A17

*For sale by the National Technical Information Service, Springfield, Virginia 22161

GSFC 25-44 (10/77)